WATER FLOODING OF OIL SANDS
IN BUTLER AND GREENWOOD COUNTIES, KANS.

BY J. P. POWELL

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May 1956

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J. P. Powell[1]

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INTRODUCTION AND SUMMARY

Records show that systematic water flooding was begun as early as 1935 in Greenwood County and in 1937 in Butler County. Water flooding on some earlier projects in Greenwood County were described in a Bureau of Mines Report of Investigation.[2] This report presents a discussion of 4 projects - 2 in Butler County, 1 in Greenwood County, and 1 in Butler and Greenwood Counties. The location of these projects is shown in figure 1. The projects have been in operation 6 to 12 years and have recovered about 6.6 million barrels of additional oil from the injection of 84.7 million barrels of water.

Three of the projects take advantage of the elevation of the nearby hilly terrain, and water from the treating ponds flows by gravity through the filters into the clear-water tanks. By utilizing gravity flow, fewer pumps and less electrical energy is required, resulting in more economical operation.

On one project water treating is accomplished principally in three wooden tanks. In the process the untreated water is mixed with chemicals as it enters the first tank, where some settling occurs. The other two tanks permit further settling, and the treated water flows from the third tank through the filter into the clear-water pond.

Discussion of the individual projects includes information on the early history, the source and treatment of water used for flooding, production-decline curves, typical electric logs and core analyses, water analyses, sketches of the water-conditioning systems, and results of water flooding.

ACKNOWLEDGMENTS

This report on water-flooding in Butler and Greenwood Counties, Kans., was prepared by the Bureau of Mines under a cooperative agreement with the State of Kansas.

The writer gratefully acknowledges the cooperation of the officials and employees of the oil companies operating the water-flooding projects described, who made this report possible by furnishing engineering and statistical data regarding their respective projects.

DISCUSSION OF INDIVIDUAL PROJECTS

Morrison Producing Co. Fox-Bush Project

The Morrison Producing Co. properties in the Fox-Bush field in Butler County, Kans. (fig. 2) cover 1,980 acres of which 990 were included in the water-flooding

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[2] Grandone, Peter, History of Water Flooding of Oil Sands in Kansas: Bureau of Mines Rept. of Investigations 3761, 1944, 146 pp.

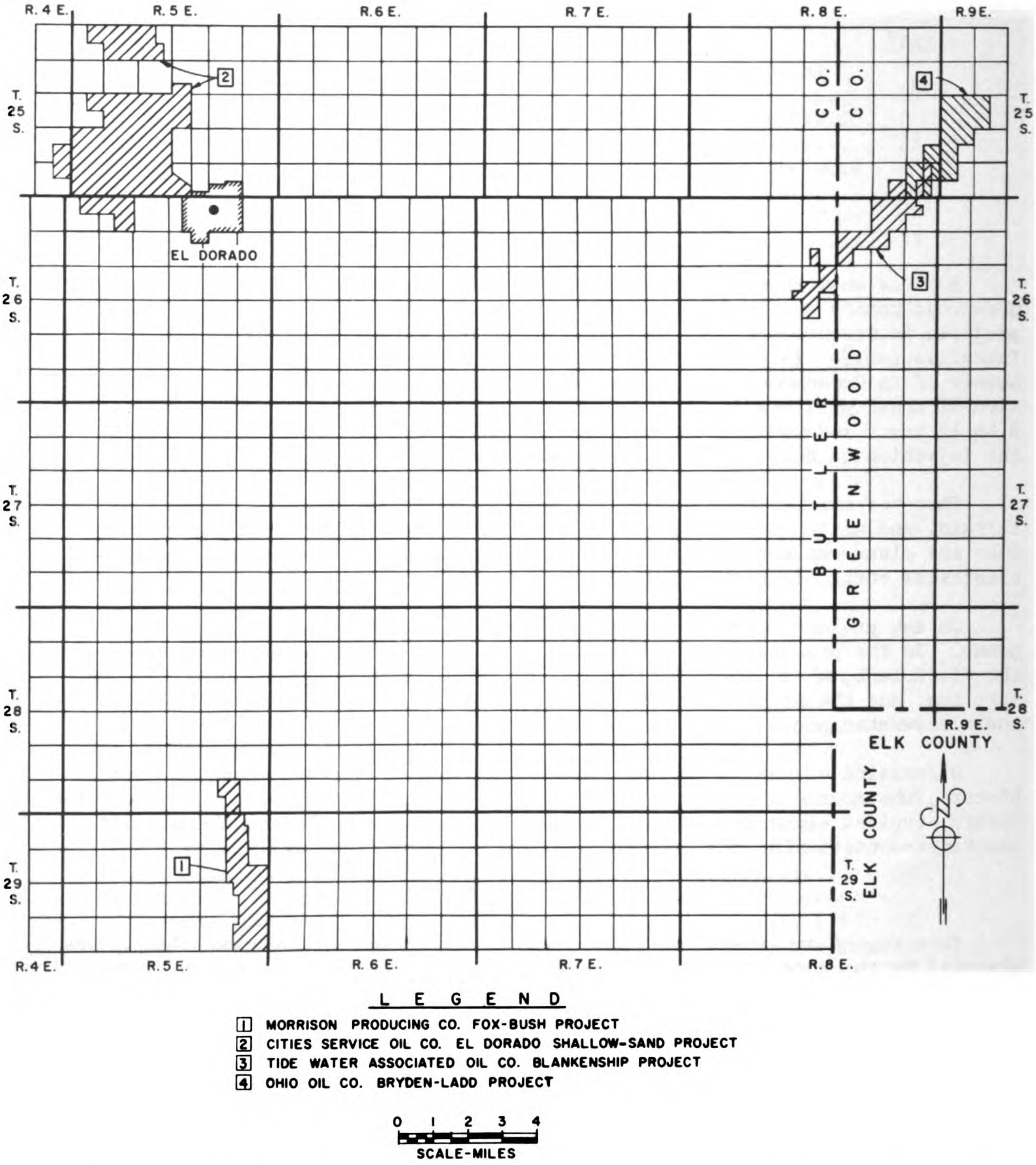
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
T. 25 S.
T. 26 S.
T. 27 S.
T. 28 S.
T. 29 S.
EL DORADO
BUTLER CO.
GREENWOOD CO.
ELK COUNTY
1
2
3
4
LEGEND
1 MORRISON PRODUCING CO. FOX-BUSH PROJECT
2 CITIES SERVICE OIL CO. EL DORADO SHALLOW-SAND PROJECT
3 TIDE WATER ASSOCIATED OIL CO. BLANKENSHIP PROJECT
4 OHIO OIL CO. BRYDEN-LADD PROJECT
0 1 2 3 4
SCALE-MILES

Figure 1. - Map showing locations of four water-flooding projects in Butler and Greenwood Counties, Kans., Jan. 1, 1956.

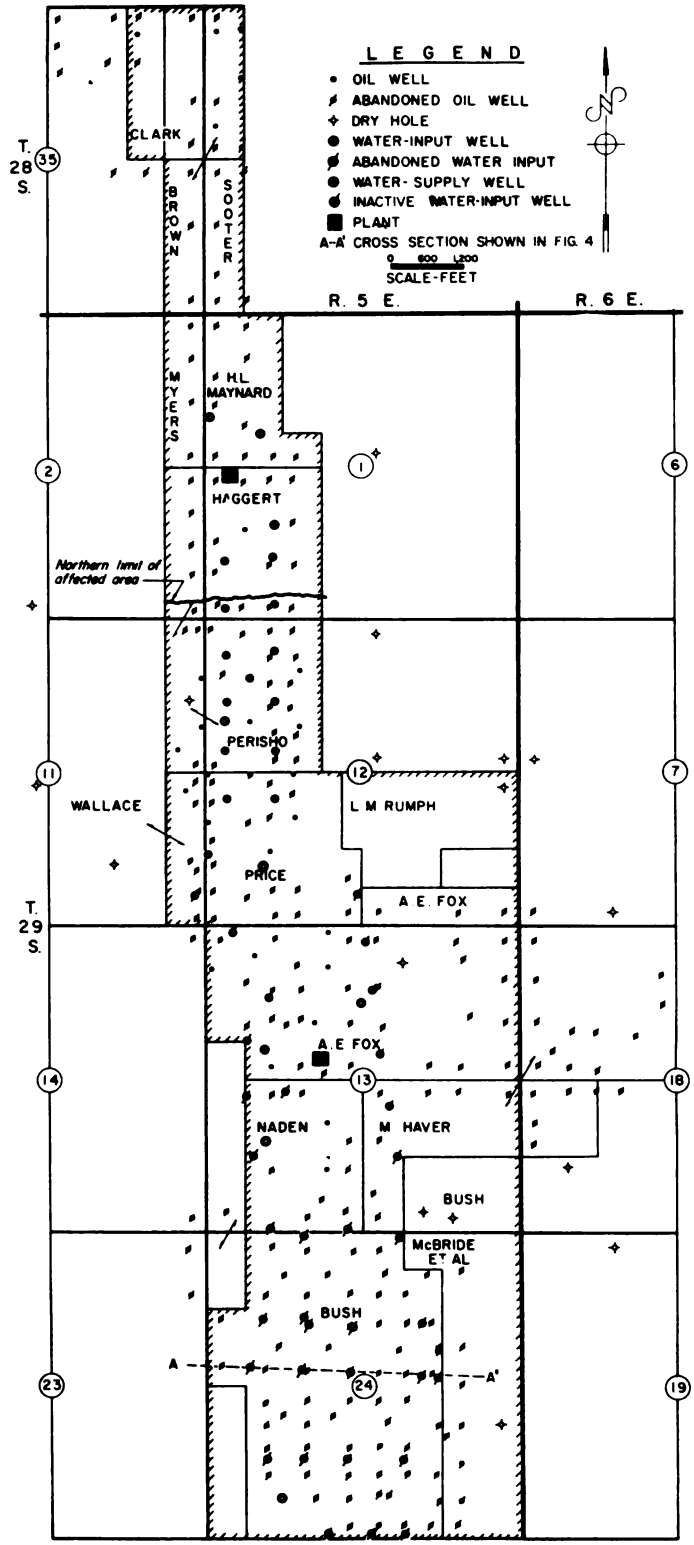

Figure 2. - Morrison Producing Co. Fox-Bush project, Butler County, Jan. 1, 1956.

project at the end of 1955. The royalty interests have been unitized. Waterflooding operations were begun in 1943 in sec. 24, T. 29 S., R. 5 E., in Butler County, Kans. The project has been developed and expanded sporadically during the ensuing years. The Bartlesville sand is flooded at an average depth of 2,800 feet and has an average thickness of 36 feet. The sand is of the shoestring type common to many sands in the pools in Butler and Greenwood Counties, Kans., as described by Bass.[3/] Analyses of cores indicate that the formation had, before water flooding, the following average characteristics: Porosity, 16 percent; permeability, 130 millidarcys; oil saturation, 25 percent; and water saturation 44 percent. A representative electric log and a core analysis are shown in figure 3. Analyses of cores from wells shown in cross section A-A' (fig. 4) indicate that the middle part of the shoestring sand is highly permeable and that the lower part often is water saturated. The delayed drilling of the oil wells and the fracturing of edge producing wells are techniques that have been used successfully on this project and are now followed as regular operating practices.

History Before Flooding

The discovery well in the Fox-Bush field was drilled in 1917 in sec. 17, T. 29 S., R. 5 E. Oil was produced by primary methods for about 6 years, after which vacuum was introduced into the field. Severally centrally located plants were constructed for processing gas from the wells. The natural gasoline was removed from the gas produced under vacuum, and the residue dry gas was used in the field as fuel. Originally the derricks were left over the wells, which were pumped off the beam by individual 20- to 25-hp. gas engines. By the late 1930's, however, most of the wells were operated from central bandwheel powers. When water injection was begun in 1943 most of the oil wells in the field had been abandoned. The pilot flood used some of the original 20- to 25-hp. gas engines to pump individual wells, but most of these engines have since been replaced with electric motors. On all of the more recent developments, individual electric pumping units are used exclusively. Data on the annual rates of oil production before flooding, are not available, but 5,149,456 barrels of oil was recovered before water injection by primary production methods and by use of vacuum. This is a recovery of about 3,700 barrels per acre from the 1,395 developed acres.

Method of Completing and Operating Wells

The water-input wells are drilled with rotary equipment into the top of the oil sand. To determine precisely the top of the "pay sand" the wells are cored through an overlying shale and into the top of the oil sand. Four and one-half or 5 1/2-inch casing usually is set about 1 foot into the pay sand and cemented with 100 sacks of cement, using a Baker triplex or a Larkin Cementrol shoe. After the cement has hardened, the cement plug and the oil sand are drilled with cable tools. The sand face is washed with water; but, if the return water is not clear after thorough washing, 50 to 100 gallons of mud acid is used. The well then is connected to the waterline, and the rate at which water can be injected is determined. If the well does not take water at a reasonable rate or if the rate of injection slows appreciably after injection of about 300,000 barrels of water, the well is hydraulically fractured, using water and 1,500 to 2,000 pounds of sand. Water usually is injected into most wells at a rate of 500 to 600 barrels per well per day.

[3/] Bass, N. W., Origin of Shoestring Sands in Greenwood and Butler Counties, Kans.: Kansas Geol. Survey Bull. 23, 1936, 135 pp.

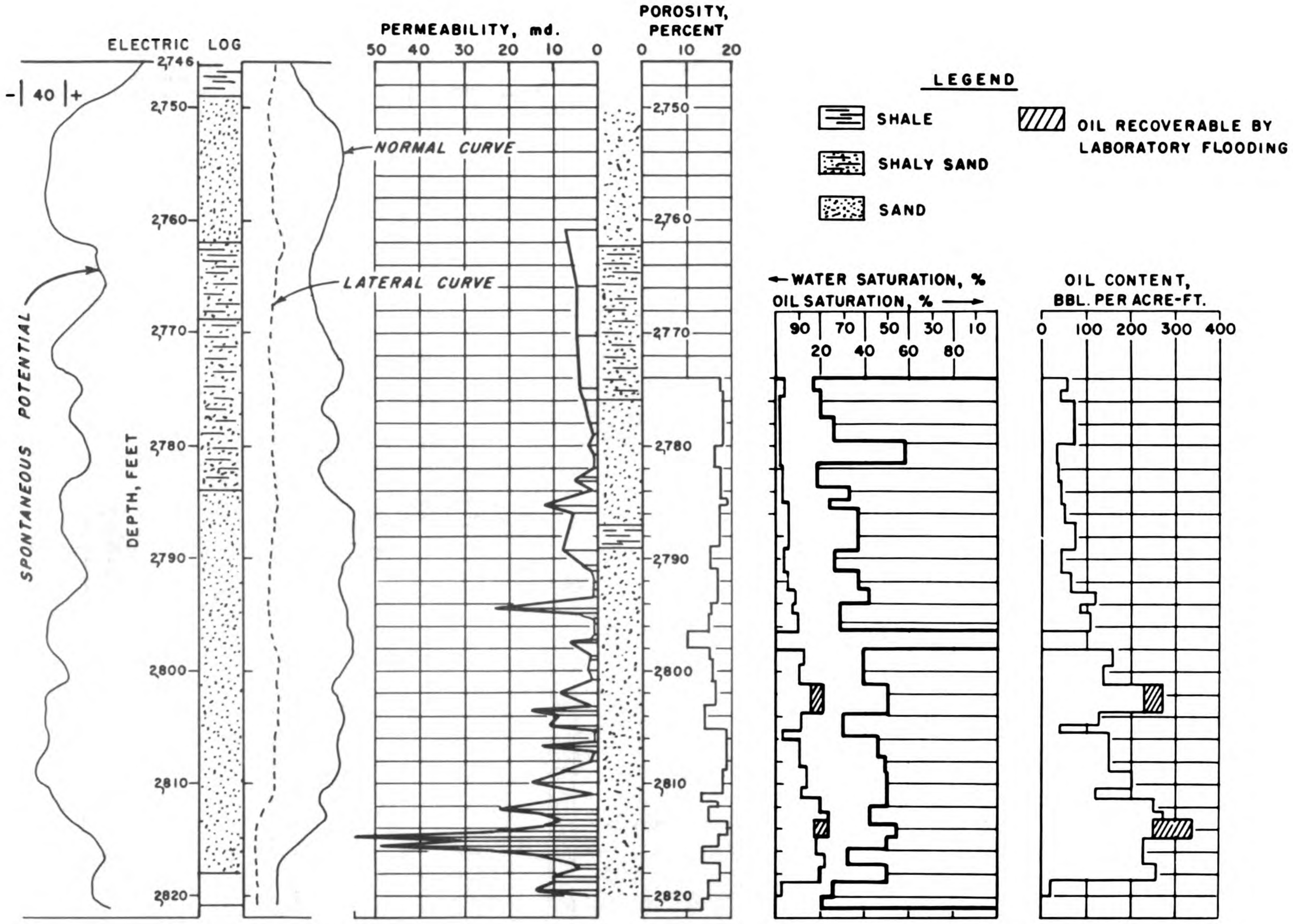

Figure 3. - A representative electric log and core analysis, Morrison Producing Co. Fox-Bush project, Fox-Bush field, Butler County, Kans.

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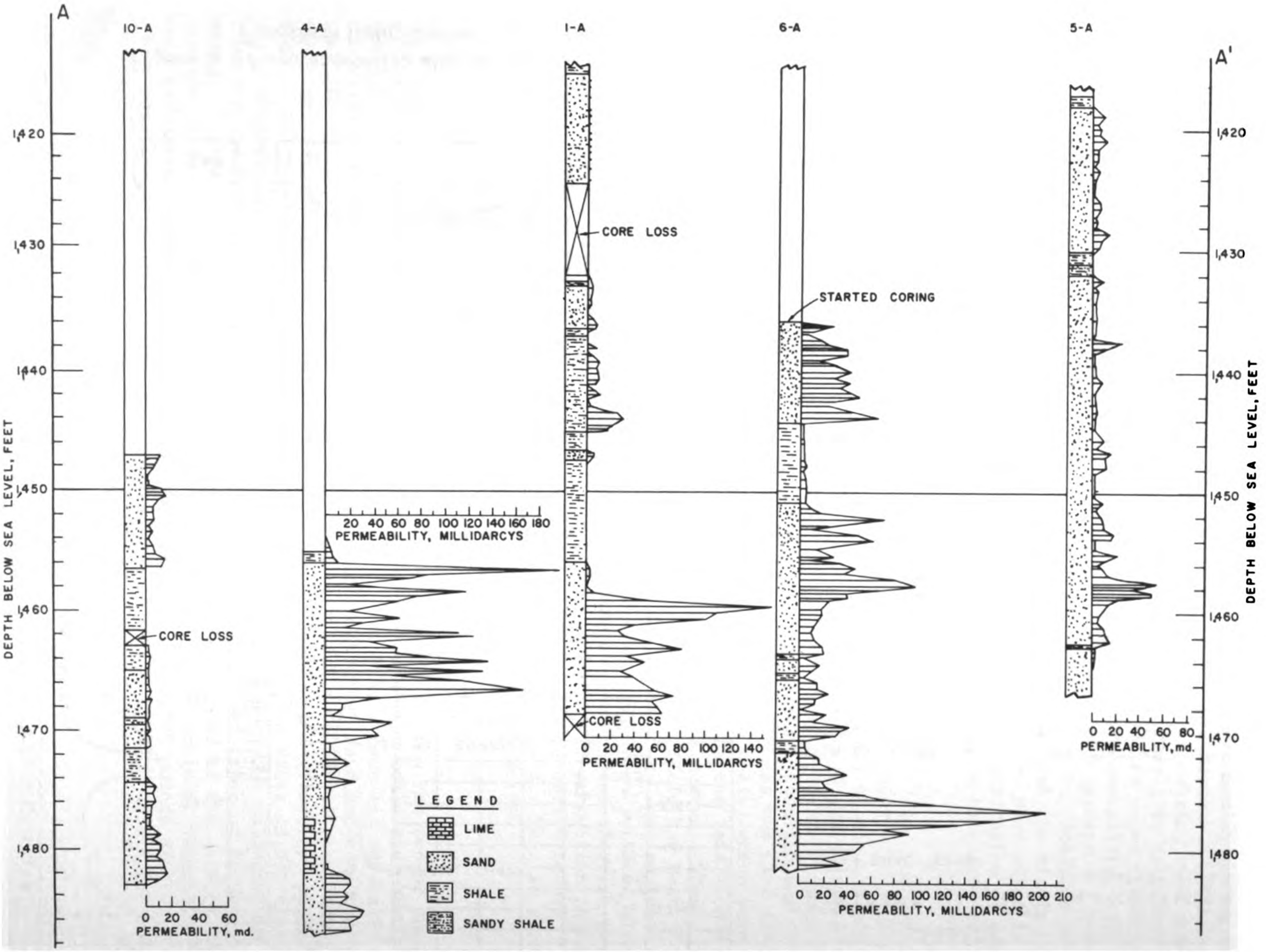

Figure 4. - Permeability of Bartlesville sand in wells in Section A-A', Morrison Producing Co. Fox-Bush projects.

The producing wells are drilled and completed in the same manner as the input wells. If a well does not produce at a satisfactory rate it is hydraulically fractured, using an average of 2,000 pounds of sand and 1,500 gallons of lease oil. Oil wells drilled along the edge of the field where the formation is thin or interbedded with shale are hydraulically fractured when completed. Since this method of completion was adopted, more oil has been recovered per well, although the water-oil ratio has been increased. None of the wells are drilled entirely through the sand. Only a few old wells have been reworked and used in the flood pattern. The inactive input wells on the Fox leases (see fig. 2) will be used later to flood the eastern part of the lease.

Source and Treatment of Water

During the first 4 years of water injection an aquifer at a depth of 300 feet was the only source of brine. In 1947 a well was completed in the Arbuckle limestone formation to supplement this supply. The Arbuckle brine was satisfactory but unnecessary after abandonment of some input wells on the Bush lease and adoption of new completion and development practices on other leases reduced the supply-water requirements. Pumping of water from the shallow wells is more economical. The Arbuckle well now is maintained on a standby basis. In 1953, a second plant was constructed, and 4 additional supply wells were completed in the shallow water sand with 7-inch casing set and cemented to the surface. The water-bearing formation, which is about 10 feet thick (known locally as the Wreford sandy lime), was acidized with 1,000 to 1,200 gallons of hydrochloric acid. A 3-hp. Reda submersible pump in each well forces the water to the surface and thence to a settling pond. These wells are spaced at wide intervals along the shoestring, each with a daily capacity of 800 to 900 barrels of water. They are used also to supply water for the drilling rigs. Brine produced with oil also is used for flooding. Two water-treating plants serve the project, one on the Haggart lease in sec. 1, T. 28 S., R. 5 E., and the other on the A. E. Fox lease in sec. 13, T. 28 S., R. 5 E. The two plants are similar, but the Haggert plant (the newer and more modern) will be described in detail.

Figure 5 is a sketch of the Haggert plant. The water from the tank battery is collected in a 100-barrel wooden tank, where any oil that might have been carried through from the gunbarrel[4/] is skimmed off. From the skimming tank the water flows over an aerating platform and falls into the settling pond to be mixed with the water from the supply wells. The earthen settling pond, which is lined with an asphaltic material (Gulf-Seal) to prevent seepage, is 150 by 85 feet and is divided into 2 parts by an earthen baffle through which the water flows in two 10-inch conduits. Water in the settling pond enters a 4-inch floating suction line, and a Mission 3- by 4-inch centrifugal pump powered by a 7 1/2-hp. electric motor forces it into the first of a series of 3 wooden, 500-barrel, treating tanks.

The water enters the treating tank at the top of a flume that extends almost to the bottom of the tank. A chemical mixture supplied by the Treatrite Chemical Co. is added and mixed with the water. The treated water flows over and then under other baffles in the tank before flowing to the second tank. The second tank is provided with a single baffle under which the water passes before rising to overflow into the third tank. The third tank is not equipped with baffles. From it the water flows to four open-type rapid-sand filters. Sludge is removed through a line to the settling pond.

[4/] The term, "gunbarrel" as used in this report refers to the tanks used for separating the oil and water.

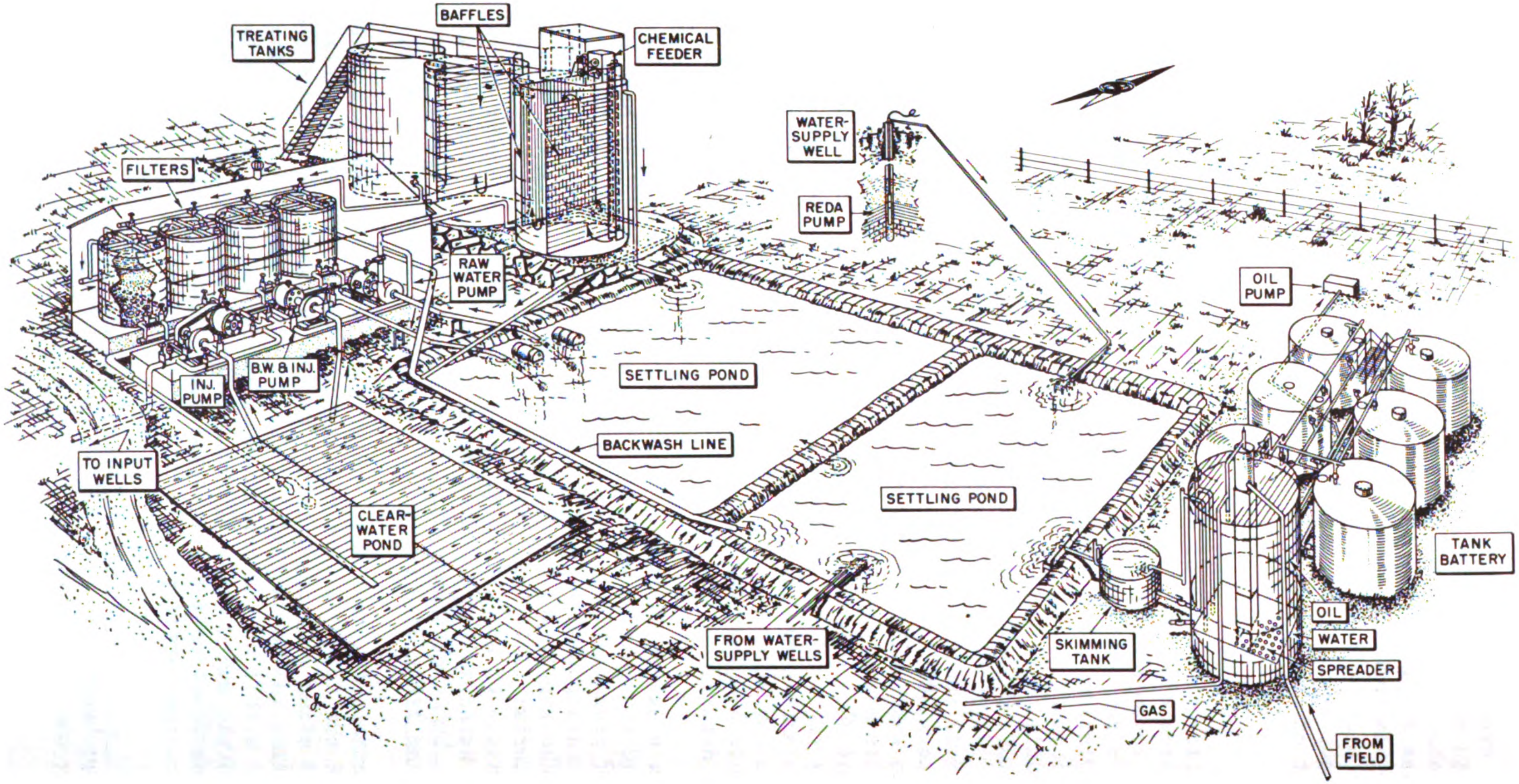

Figure 5. - Water-treating plant of Morrison Producing Co. Haggert lease, Fox-Bush project, Butler County, Kans.

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The filters are wooden tanks filled with graded gravel and filter sand. Troughs in the form of a cross at the top of each filter provide for even distribution of the incoming water and for collection of the backwash water. A perforated collector ring provides for even flow of water from the bottom of each filter to the clear-water pond (an earthen pit approximately 30 by 30 feet by 6 feet deep). It is lined with Gulf-Seal to prevent seepage and covered to prevent contamination from dust and debris. Each filter is equipped with a float that regulates the flow of water to the unit and an overflow line to carry the backwash water to the settling pond. Two Mission centrifugal pumps connected in series or "staged" force the water from the clear-water pond into the distribution lines at a pressure of 60 p.s.i.; however, the piping is arranged to permit 1 pump to be used for backwashing the filters.

To provide for greater flexibility of operation, the Haggert and Fox tank batteries are interconnected, and the two plants discharge treated water into a main distribution line.

An arrangement of floats and electrodes in the ponds and tanks provides for automatic operation of the treating and pumping system.

Analyses of samples of the untreated and treated brines are shown in table 1.

Results of Flooding

Sporadic development and the delayed drilling of the producing wells have caused irregularities in annual rates of oil production, which ranged from a peak of about 113,000 barrels of oil in 1946 and a low of 46,000 in 1953.

During the first years of flooding the injected water channeled through the bottom of the sand or through the gas sand on top as well as through a very permeable section in the middle of the sand. This resulted in a large water-injected to oil-produced ratio that reached a peak in 1951 when the annual ratio was 61:1 and the cumulative ratio increased to 36:1. Selective plugging of the bypassing zones with cement and plastic was unsuccessful. A modification of well-completion practices, by cementing off the top gas sand and highly permeable section in the bottom of the sand, has aided in decreasing the bypassing of the water. Also a change in the flood pattern to take advantage of the more permeable zones, by locating the input wells in the middle of the shoestring, has resulted in a better flooding efficiency. During 1954 and 1955, when these modifications were first tried, the annual water-injected to oil-produced ratio declined to 5:1 in 1954 and 9:1 in 1955 and caused a decrease in the cumulative ratio to 29:1 at the end of 1954 and 26:1 at the end of 1955. The flooding from the center of the shoestring toward the outside edges appears to be most effective on this project.

The results of water flooding on the Fox-Bush project are shown in figure 6. Over 1,075,000 barrels has been recovered to date from the 990 acres included in the project. Although many older leases in the southern part of the project have passed their peak rate of production and some have been abandoned (approximately 800 acres had been abandoned by 1953), the project reached a new peak rate of production in 1955 that was more than 50 percent above the earlier year. Even greater production is anticipated for 1956.

The following summary of operations includes many data on the project. It will be noted that the recovery by water flooding now averages slightly over 1,000 barrels per acre. It is not possible, from the production curve, to predict the ultimate recovery.

TABLE 1. - Mineral analyses of flooding waters, Morrison Producing Co. Fox-Bush project, Butler County, Kans.

Radical	Supply well		Produced brine		Mixed brine, untreated		Clear water	
	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)
Calcium (Ca)	102	3.26	6,110	7.68	5,450	7.30	5,570	7.48
Magnesium (Mg)	96	5.06	1,950	4.33	1,740	4.12	1,800	4.27
Sodium (Na)....................	1,500	41.68	34,700	37.99	33,100	38.58	32,000	38.25
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	420	4.41	104	.04	114	.05	109	.05
Sulfate (SO_4)	300	4.00	429	.22	558	.31	553	.31
Chloride (Cl)	2,300	41.59	70,000	49.74	65,600	49.64	65,400	49.64
Total solids	4,718	100.00	113,293	100.00	106,562	100.00	105,432	100.00
Hydrogen sulfide (H_2S)	None		None		None		None	
Barium (Ba)	None		None		None		None	
Specific gravity	1.007		1.082		1.077		1.077	

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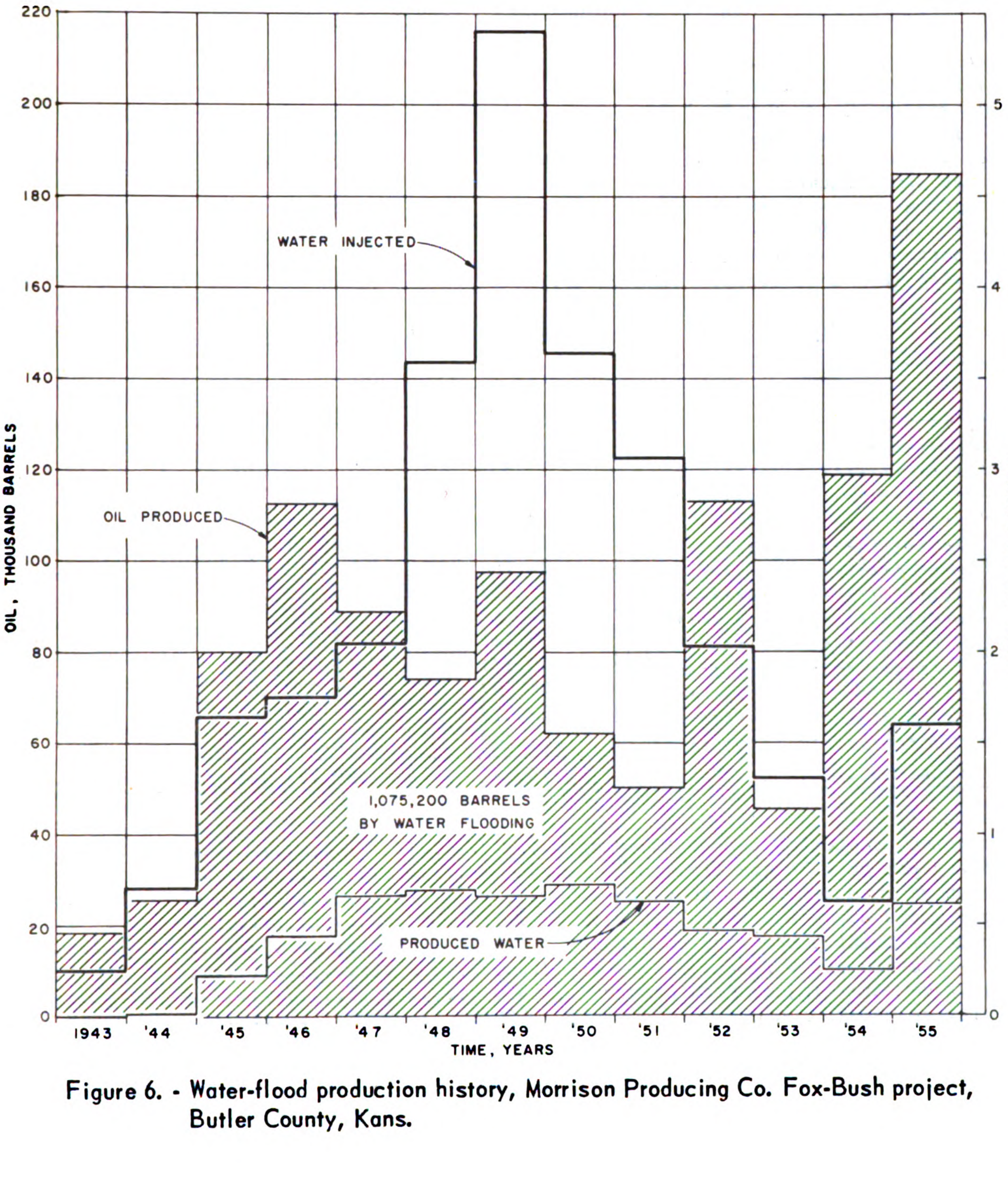

Figure 6. - Water-flood production history, Morrison Producing Co. Fox-Bush project, Butler County, Kans.

Summary of operations
Morrison Production Co. Fox-Bush project

Location - secs. 35 and 36, T. 28 S., R. 5 E., and secs. 1, 12, 13, and 14, and 24, T. 29 S., R. 5 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,800 feet
Average sand thickness - 36 feet
Productive area - 1,980 acres
Area flooded - 990 acres
Well pattern - 5-spot with 15-acre spacing (808 feet between like wells.)

Type of water - brine
Type of system - open
First injection - 1943
First oil increase - 1943
Status - active
Gravity of oil - 42° to 43° API
Viscosity of oil - 2.9 cp. at 100° F.

Oil and water produced, water injected, by years, bbl.

Year	Oil produced	Water injected	Water produced
1943[1]	18,621	274,807	608
1944	25,839	707,870	13,925
1945	80,404	1,642,931	231,456
1946	112,792	1,757,418	443,412
1947	88,806	2,059,574	672,883
1948	74,760	3,590,639	693,490
1949	97,767	5,410,479	653,273
1950	62,348	3,650,320	723,650
1951	50,482	3,072,220	630,465
1952	113,321	2,025,320	474,520
1953	45,707	1,300,407	430,740
1954	119,077	627,641	256,187
1955	185,308	1,604,609	624,625
Total	1,075,232	27,724,235	5,849,234

	Bbl.
Cumulative production before flooding	5,149,456
Recovery per acre before flooding[2]	3,691
Cumulative production by water flooding	1,075,232
Recovery per acre (990 acres)	1,086
Cumulative total production to January 1, 1956	6,224,688
Total recovery per acre[2]	4,462
Cumulative water injected to January 1, 1956	27,724,235
Cumulative water produced to January 1, 1956	5,849,234

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[1] Annual primary oil-production data not available; water flooding begun.

[2] The oil production by primary method included only 1,395 acres of Morrison Producing Co. leases. These figures are based on that area.

Summary of water-flood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected —oil-produced ratio
Dec. 31, 1943	14	4	2	1,330	15
Dec. 31, 1944	156	7	7	285	22
Dec. 31, 1945	200	14	13	624	21
Dec. 31, 1946	285	19	13	834	18
Dec. 31, 1947	285	19	13	1,145	20
Dec. 31, 1948	565	30	13	710	25
Dec. 31, 1949	690	33	20	723	31
Dec. 31, 1950	790	33	23	711	34
Dec. 31, 1951	790	33	23	774	36
Dec. 31, 1952	830	33	23	874	33
Dec. 31, 1953	890	37	15	866	33
Dec. 31, 1954	973	7	19	915	29
Dec. 31, 1955	990	13	20	1,086	26

Cities Service Oil Co. El Dorado Shallow-Sand Project

The El Dorado Shallow-sand water-flooding project (fig. 7) of the Cities Service Oil Co. in the El Dorado field is chiefly in T. 25 S., R. 5 E., with parts of the various units extending into T. 25 S., R. 4 E., and T. 26 S., R. 5 E., Kansas. The formation flooded is known locally as the 660-foot sand and has been described by Fath[5] as a member of the Admire shale section of the Wabaunsee formation of Pennsylvanian age. The thickness of the sand ranges from 10 to 20 feet. Core analyses show that the formation is composed of sand interbedded with shale, which reduces the average net sand thickness to about 10 feet. The porosity is high - about 29 to 30 percent - and the permeability varies between 150 and 1,500 millidarcys. The operator has estimated that the average oil saturation of the sand before flooding was about 30 percent and the average water saturation about 50 percent. A comparison of an electric log to a core analysis taken on the flood is shown in figure 8.

History Before Flooding

The Shallow 660-foot sand was the first formation to produce oil in the El Dorado field. The discovery well was drilled in September 1915, and it still is producing oil (1956). The original wells in the 660-foot sand produced 40 to 80 barrels of oil daily, although a few wells produced at a rate of 100 to 200 barrels daily. The wells flowed for a short time, but the rate of production declined rapidly, and it was soon necessary to equip them for pumping. The productivity of the wells bore slight relationship to their location on the structure. Recovery by primary methods from the 4,985 producing acres included in the project is calculated to be about 14.5 million barrels of oil, equivalent to 2,910 barrels of oil per productive acre.

In 1924 and 1925 a pilot air-drive test was tried in sec. 29, T. 25 S., R. 5 E., using 1 air-injection well and 8 oil-producing wells. Good results were obtained, so a full-scale air-drive operation was begun in 1926 which, when fully

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[5] Fath, A. E., Geology of the El Dorado Oil and Gas Field: Kansas Geol. Survey Bull. 7, 1921, 187 pp.

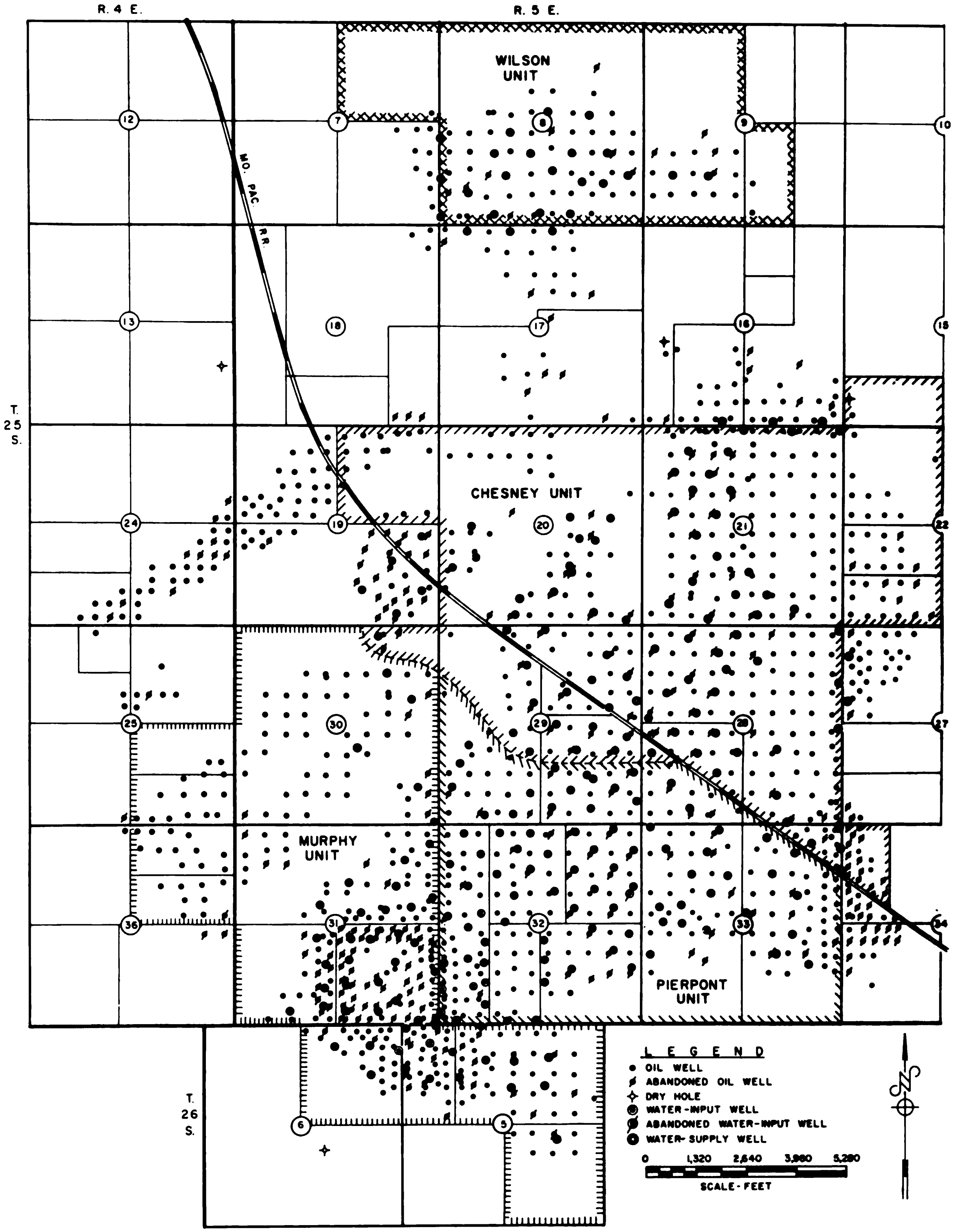

Figure 7. - Cities Service Oil Co. El Dorado Shallow flood, Butler County, Kans., Jan. 1, 1956.

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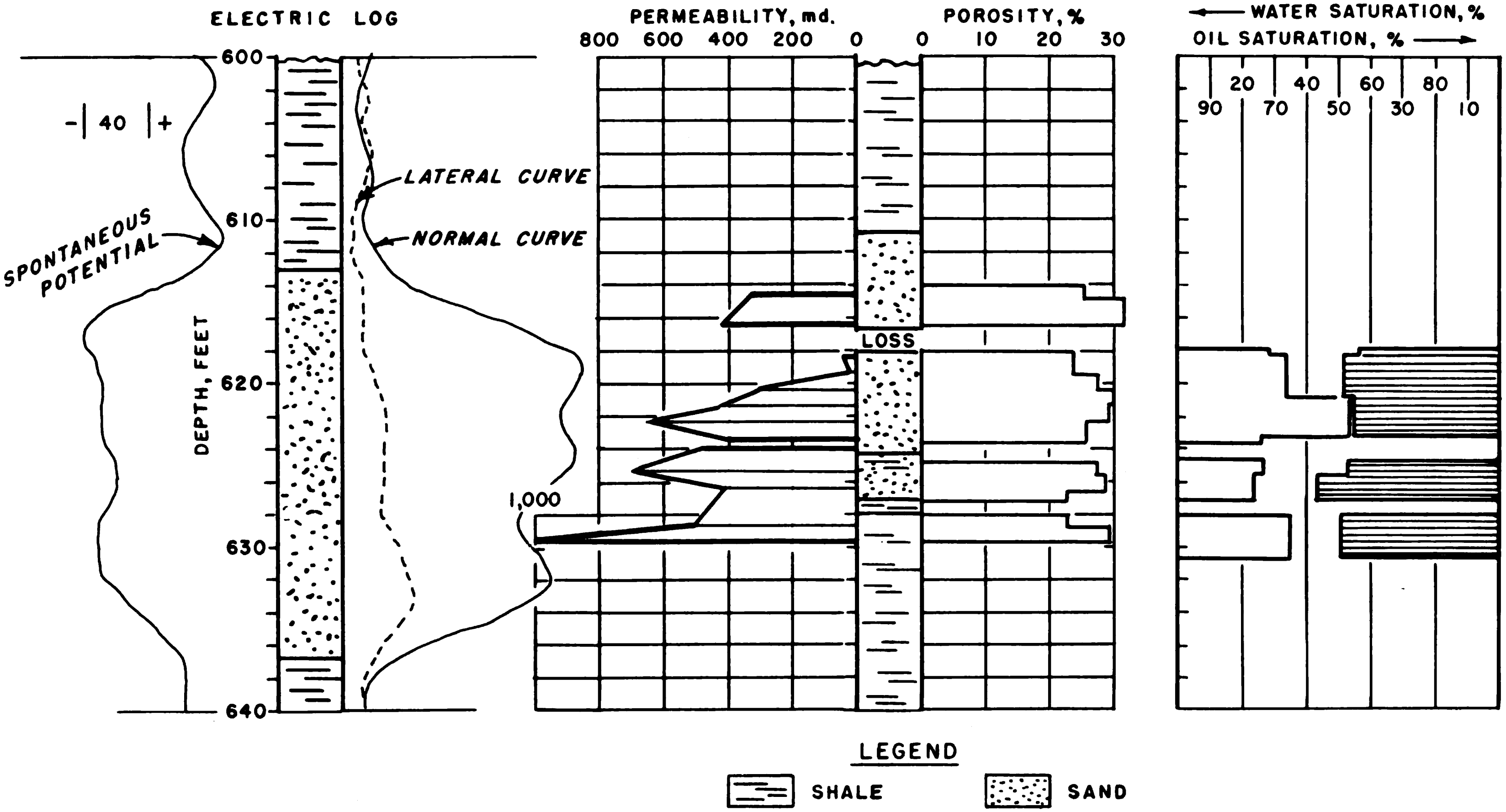

Figure 8. - Representative electric log and core analysis, Cities Service Oil Co. El Dorado Shallow-sand project, El Dorado field, Butler County, Kans.

developed included 110 air-injection wells that affected about 500 oil wells. Later the project was expanded gradually, so that about 770 oil wells were effected. The air drive was continued on each lease until 1954, when the lease was converted to water flooding. About 12.2 million barrels of oil was recovered by the air drive in addition to the 14.5 million barrels of oil recovered by primary methods. The recovery by airdrive amounted to 2,460 barrels of oil per acre, bringing the total recovery before water injection to 5,370 barrels per acre.

Development of Flood

A pilot water flood was begun on the Hegberg lease in 1937, using fresh water purchased from the city of El Dorado. A coagulant was added to the water, and it was filtered before being injected. Even though the operation was small initially, water was injected at the rate of about 200 barrels per day at an average wellhead pressure of 50 p.s.i.; however, within 60 days the rate had declined to 100 barrels daily at a pressure of 600 p.s.i.. A packer leak then developed; and while the well was being reconditioned, injection into a second well was begun. Although water was injected into these two wells for several months, no increase in the rate of oil production was obtained, and the test was abandoned in March 1939. A total of 190,000 barrels of water was injected. Failure of the test is attributed to swelling of clays in the sand in contact with fresh water.

In 1947 a second pilot test was begun on the Pierpont lease. Four new input wells were drilled between existing oil wells, so that the spacing of the input well was about 6 acres per well. These wells were drilled with a rotary, and 4 1/2-inch casing was set and cemented at the top of the sand. The sand in each well was shot with 5 to 10 quarts of nitroglycerin, and the holes were then cleaned out with cable tools. A packer on cement-lined tubing was set in the bottom joint of casing in each well. The surface equipment consisted of a corrosion-resistant meter and flow valve.

Water for this test was obtained from a well producing both oil and water from the Arbuckle limestone formation. After being separated from the oil in the gunbarrel the water was handled in a closed system without chemical treatment. The input wells took the brine at a reasonable rate and pressure, and within 6 months an increase in the rate of oil production from surrounding wells was noticed. The rate of production from the oil well in the center of the project increased to 30 barrels per day, while oil wells adjacent to the pattern increased from a normal rate of 1 barrel to 7 or 8 barrels per day.

When it became apparent that the pilot project would be successful, six new injection wells were added to the project. There was little further development for about 3 years, but since 1950 the project has been expanded rapidly. By the end of 1955 nearly 4,000 acres was included in the project, with development still in progress. Over 200 input wells were affecting 448 producing wells and the daily rate of oil production from the flood project exceeded 4,600 barrels.

In developing the project the field was divided into several operating units, and a water treating and pumping plant was constructed to serve each unit. The boundaries of each of the units are shown by different types of hatching in figure 7. The Pierpont plant(the first one built)was expanded in 1948, the Chesney plant was put into operation in April 1953, and the Wilson plant was activated in February 1954. A plant now under construction on the Murphy unit will be put into operation early in 1956.

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Method of Completing and Operating Wells

Several methods of well completion using both cable and rotary drilling have been tried on the flood. Some wells were shot with 5 to 10 quarts of nitroglycerin each, and some old oil-producing wells were used as input wells when they fit into the well pattern, but these methods proved unsatisfactory. The most recent practice is to drill the input wells with rotary tools, using mud to drill and set pipe and clear salt water to drill and complete. The wells are drilled 1 to 2 feet into the sand and casing is set to bottom and cemented. After the cement has set the oil sand is drilled, and the sand face reamed and flushed clean. Input wells completed by this method appear to take water more readily than the wells completed with cable tools and shot with nitroglycerin. The few wells that do not take water at an adequate rate are shot and cleaned out with cable tools.

Old oil wells are used in the flood unless contaminated by water from casing leaks; it is necessary to redrill about 25 percent of the oil wells. Some new wells were completed with rotary tools and with 4 1/2-inch casing set and cemented in the top of the sand. The sand is then drilled with cable tools. Recent practice is to complete all of the oil wells with cable tools, using the 7-inch casing reclaimed from the plugged wells. All of the producing wells were shot originally with 10 to 15 quarts of nitroglycerin per well. The wells are equipped for pumping with individual electrically powered units. Facilities for individual well-production tests are provided at each tank battery.

Source and Treatment of Water

The method of conditioning water at the Chesney unit is considered typical of the units in the project and is described in detail. The principal source of water for the project is water produced with the oil, not only from the Shallow sand but from the several deeper producing formations in the El Dorado field, including the Arbuckle, Kansas City, Marmaton, Viola, and Simpson formations. A common waterline supplies all units with produced brine from the field. Three water-supply wells, completed in the Arbuckle limestone and equipped with Reda submersible pumps, supplement the produced water.

At the Chesney plant (fig. 9) brine from field enters the aeration pond in several ways. Produced brine from a nearby tank battery flows through an open ditch into the pond, while brine from another tank battery flows by gravity to the spray and into the aeration pond. At another tank battery the produced water from the gunbarrel and from one of the Arbuckle supply wells is collected in a 1,000-barrel wooden tank and pumped to the sprays in the aeration pond.

In the aeration pond, approximately 120 feet square, are 6 spray units for aeration of the brine. The spray arms of 2-inch plastic pipe with 1-inch nozzles, are affixed to a 6-inch Transite header into which the brine flows from the supply wells and the tank batteries. The separate sprays can be regulated to provide enough pressure to obtain satisfactory aeration.

From the aeration pond the mixed brines flow through 2 aeration ditches, 1 of which is lined with Gulf-Seal and the other with a catalytically blown hot asphalt, and into a 50- by 20-foot earthen skimming pond. From the earthen skimming pond, which also has been treated with the hot asphalt to prevent seepage, the brine flows through three 8-inch pipes into a ditch lined with Gulf-Seal where a preformed chemical is added proportionally by an automatic feeder. The sealed ditch, 1.5 feet deep by 5 feet wide, has been provided with cement blocks to aid in mixing the chemical as the water flows into a rectangular settling pond of about

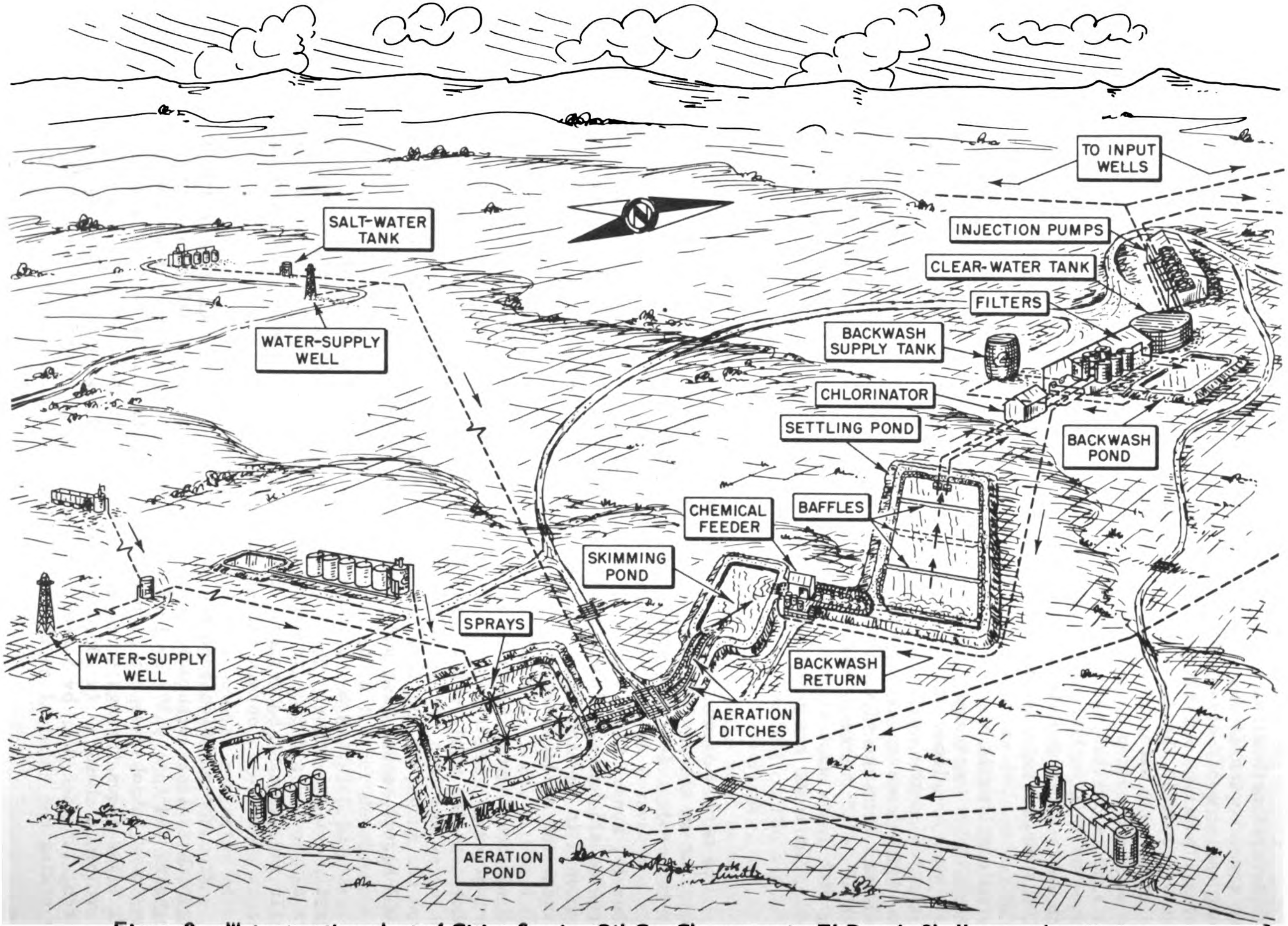

Figure 9. - Water-treating plant of Cities Service Oil Co. Chesney unit, El Dorado Shallow-sand project, Butler County, Kans.

30,000-barrel capacity. Three baffles across the pond are arranged to cause the water to flow under the first baffle, over the second, and under the third. The retention time of the water in the pond is about 3 days at the current rate of handling (10,000 barrels of water daily). The settling pond also is lined to prevent seepage. Two 8-inch Transite pipes, the inlet ends of which are supported by a float, conduct the water through a second chemical house, where about 50 pounds of chlorine is added daily to minimize the growth of bacteria. The treated water passes through the 6 filter units of the open, rapid-sand type - 8- by 8-foot wooden tanks, each filled with graded sand and gravel. A U-shaped trough installed 1 foot above the sand carries off the backwash water to a separate backwash pit, where sediment settles out and from which the water is returned to the skimming pond. A float control maintains a 3-foot head of water above the filter sand, and a 6-inch collector pipe drains the filtered water into the clear-water tank. A supply of clear, treated water is kept in a separate tank for backwashing the filter.

The clear-water tank is a covered 800-barrel wooden tank about 10 feet high. Automatic controls actuate pumps to keep the tank full and provide a 9-foot head to the intake of the pressure pumps. Three 8-inch pipes from the clear-water tank serve 5 pressure pumps, which discharge water to the distribution lines at 625 p.s.i. The pumping plant houses 6 pressure pumps, 5 of which (4 Oilwell 46 P and a Gaso triplex) supply water to the Shallow-sand flood. The other Gaso pump supplies water to a flood in the Marmaton formation. The Oilwell pumps are powered by a 75-hp. and the Gaso pumps by 100-hp. electric motors. Table 2 compares the results of mineral analyses of water at various sampling points in the system.

Results of Flooding

To January 1, 1956, about 2.5 million barrels of additional oil, equivalent to 648 barrels per acre, was recovered by water flooding in the El Dorado Shallow field. Over 30 million barrels of water had been injected, giving an oil-produced to water-injected ratio of 12:1. Development of the project has been rapid and by January 1, 1956, about 3,850 acres was included in the flooded area. Figure 10 shows the production history of the El Dorado Shallow field, and a summary of water-flood performance is included in the summary of operations. Ultimate yield as a result of water flooding is expected to be about 4.8 million barrels of additional oil, or 1,000 barrels per acre.

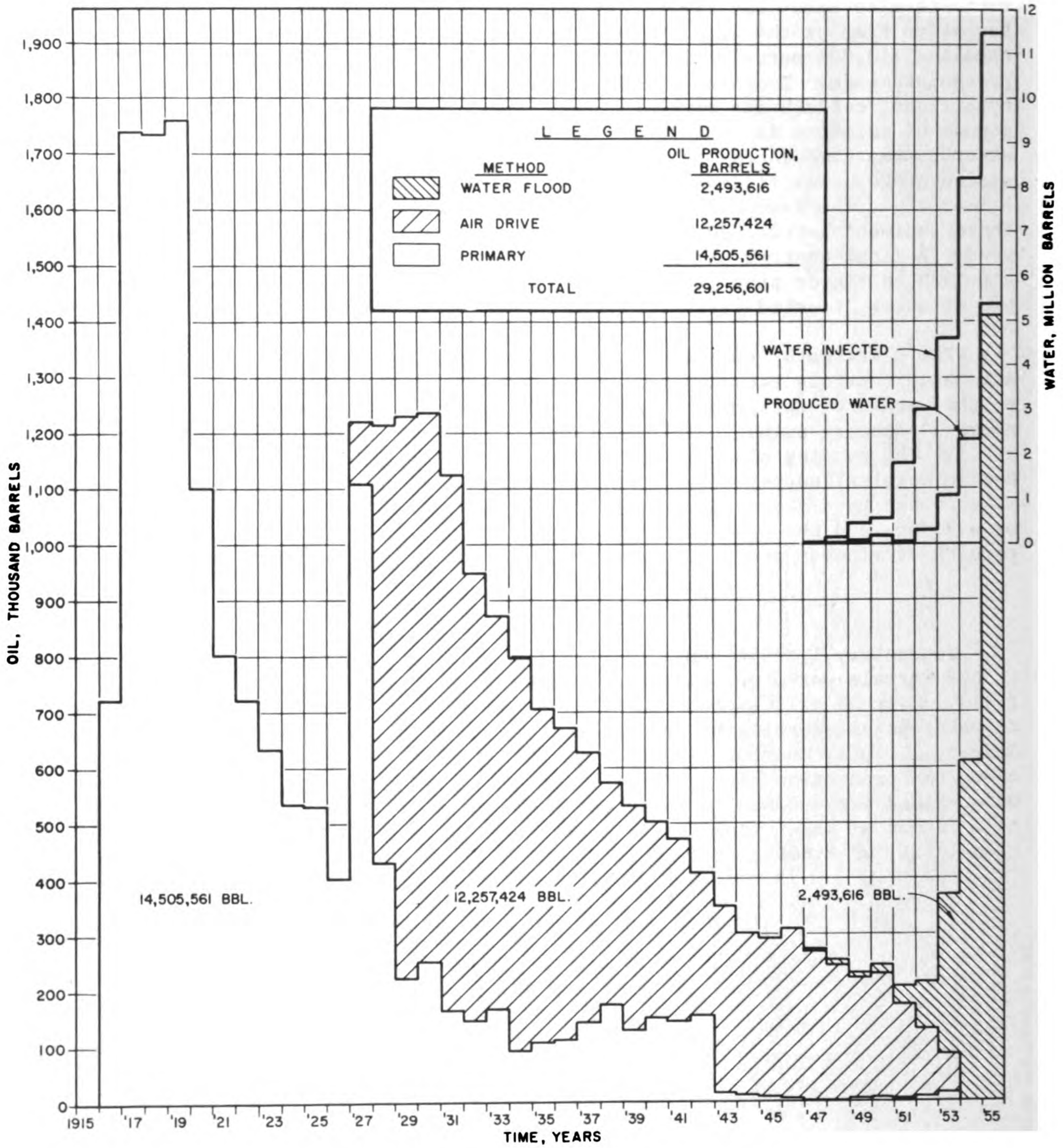

Figure 10. - Production history of Cities Service Oil Co. El Dorado Shallow-sand project, Butler County, Kans., Jan. 1, 1956.

TABLE 2. - Mineral analyses of flooding waters, Cities Service Oil Co. El Dorado Shallow-sand project, Butler County, Kans.

Radical	Supply well		Produced brine		Mixed brine, untreated		Clear water	
	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)
Calcium (Ca)	1,580	7.72	5,800	7.87	2,260	5.41	2,370	5.54
Magnesium (Mg)	418	3.61	1,750	3.91	1,220	5.16	1,180	4.88
Sodium (Na)	9,080	38.67	33,300	38.22	19,000	39.43	19,400	39.59
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	232	.37	635	.28	537	.42	605	.46
Sulfate (SO_4)	2,130	4.34	174	3.62	1,820	1.82	1,760	1.71
Chloride (Cl)	16,400	45.29	64,700	49.62	35,300	47.76	36,200	47.83
Total solids	29,840	100.00	105,359	100.00	60,137	100.00	61,515	100.00
Hydrogen sulfide (H_2S)	Yes		None		None		None	
Barium (Ba)	None		None		None		None	
Specific gravity	1.023		1.077		1.045		1.044	

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Summary of operations

Cities Service Oil Co. Shallow-sand project

Location - T. 25 S., R. 5 E., and parts of T. 25 S., R. 4 E., and T. 26 S., R. 5 E.
Sand flooded - El Dorado Shallow
Depth to top of sand - 660 feet
Average sand thickness - 10 feet
Productive area - 4,985 acres
Area flooded - 3,850 acres
Well pattern - 5-spot irregular

Type of water - brine
Type of system - open
First injection - August 1947
First oil increase - December 1947
Status - active
Gravity of oil - 36.9° API
Viscosity of oil - 4.3 cp. at 100° F.

Oil and water produced, water injected, by years, bbl.

Years	Oil production				Water	
	By primary	By air drive	Water flood	Total	Injected	Produced
1915	2,045			2,045		
1916	720,336			720,336		
1917	1,745,281			1,745,281		
1918	1,737,432			1,737,432		
1919	1,761,274			1,761,274		
1920	1,101,732			1,101,732		
1921	806,919			806,919		
1922	728,834			728,834		
1923	634,232			634,232		
1924	536,067			536,067		
1925	533,888			533,888		
1926	400,679			400,679		
1927	1,112,809	149,365		1,262,174		
1928	431,238	817,600		1,248,838		
1929	222,601	1,079,400		1,302,001		
1930	255,225	1,105,270		1,360,495		
1931	161,330	1,001,300		1,162,630		
1932	144,326	802,775		947,101		
1933	162,737	703,625		866,362		
1934	89,579	704,520		794,099		
1935	107,082	600,695		707,777		
1936	110,653	560,100		670,753		
1937	140,085	484,750		624,835		
1938	176,398	402,250		578,648		
1939	126,646	402,710		529,356		
1940	152,797	350,290		503,087		
1941	143,834	327,430		471,264		
1942	156,352	263,210		419,562		
1943	15,941	342,951		358,892		
1944	11,675	296,840		308,515		
1945	13,021	281,514		294,535		
1946	9,480	300,665		310,145		
1947	6,012	269,450	243	275,705	51,180	366
1948	3,844	248,335	4,504	256,683	146,283	23,642
1949	5,308	213,899	8,847	228,054	470,652	80,775
1950	3,738	207,867	33,249	244,854	579,340	186,163
1951	3,912	158,856	41,948	204,716	1,836,936	40,843
1952	11,915	115,127	88,608	215,650	3,029,735	324,725
1953	17,226	66,630	289,952	373,808	4,633,863	1,085,251
1954	1,078	-	610,621	611,699	8,223,858	2,339,183
1955	-	-	1,415,644	1,415,644	11,491,388	5,404,781
Total ..	14,505,561	12,257,424	2,493,616	29,256,601	30,463,235	9,485,729

	Bbl.
Cumulative production by primary to January 1, 1956	14,505,561
Recovery per acre by primary (4,985 acres)	2,910
Cumulative production by air drive	12,257,424
Recovery per acre by air drive	2,459
Cumulative production by water flooding	2,493,616
Recovery per acre (3,850 acres)	648
Cumulative total production to January 1, 1956	29,256,601
Total recovery per acre (4,985 acres) to January 1, 1956	5,869
Cumulative water injected to January 1, 1956	30,463,235
Cumulative water produced to January 1, 1956	9,485,729

Summary of water-flood performance

Years	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected—oil-produced ratio
1947	6	4	8	41	211
1948	35	10	21	136	42
1949	75	10	21	181	49
1950	120	11	26	390	27
1951	513	35	26	173	35
1952	1,227	73	124	145	34
1953	1,621	95	190	288	23
1954	2,393	158	326	450	18
1955	3,850	208	448	648	12

Tide Water Associated Oil Co. Blankenship Project

In March 1949 the Tide Water Associated Oil Co. began injecting water into wells on a pilot project on the Dickenson leases in sec. 16, T. 26 S., R. 8 E., in the Blankenship-Sallyards pool, Butler County, Kans. When the pilot flood proved successful, the project was expanded and now includes about 800 acres in 13 leases. The original pilot flood was located near the south end of the group of leases, but drilling and development commitments made it necessary to initiate water flooding on the north end, so in 1955 a new plant, which will be described in detail below, was constructed on the Hull lease in sec. 2, T. 26 S., R. 8 E. Eventually all of the leases shown on the map (fig. 11) will be flooded.

The formation flooded is the Bartlesville sand, which, in this area, is at an average depth of 2,450 feet and has an average thickness of 36 feet. The sand is of the shoestring type, the origin and geology of which have been described in detail by Bass.[6] The porosity of the sand ranges from 17 to 19 percent and the permeability from 0 to 180 millidarcys. A representative electric log and a core analysis are shown in figure 12. The average gravity of the oil produced from all of the leases is approximately 38° API.

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[6] Bass, N. W., Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas: Kansas Geol. Survey Bull. 23, 1936, 135 pp.

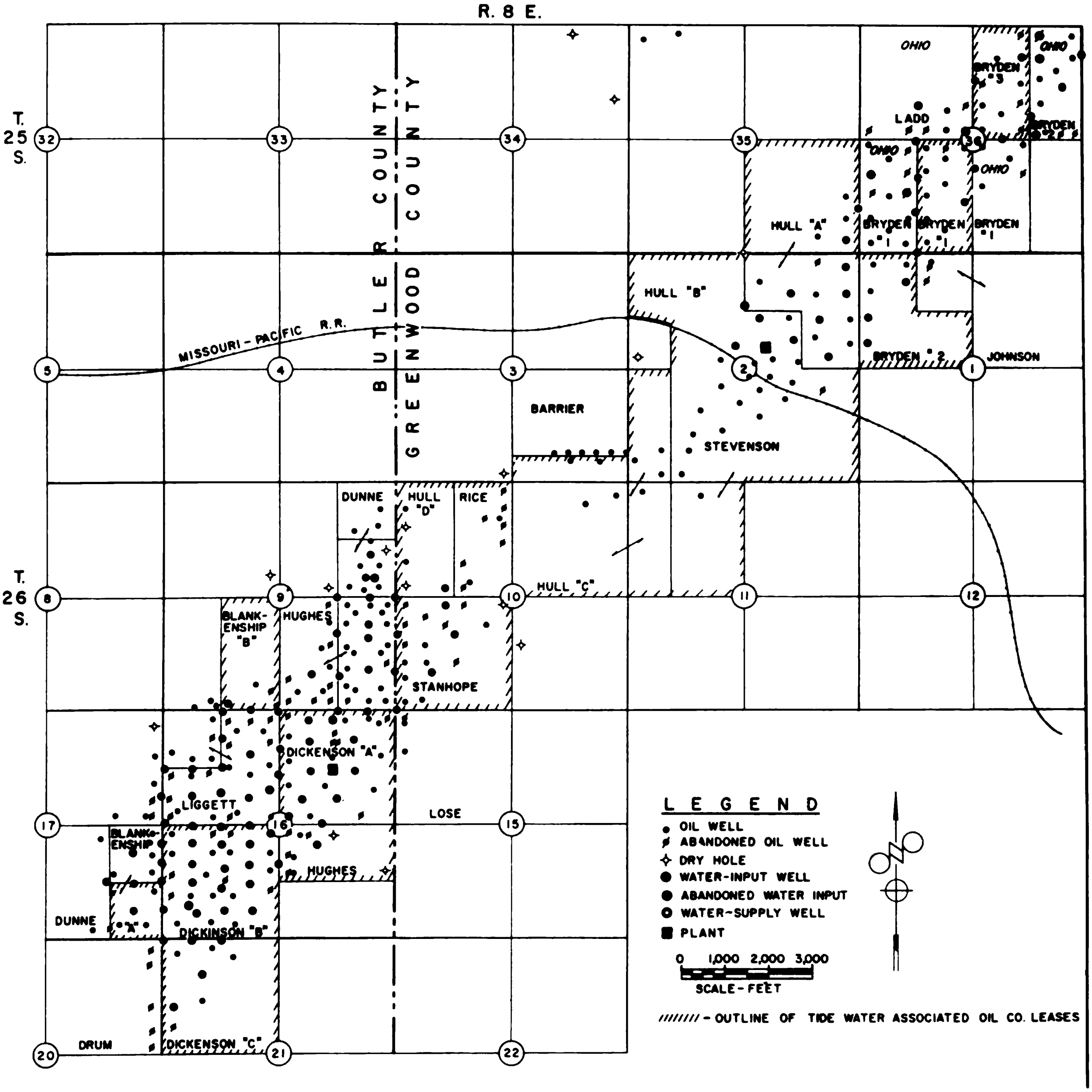

Figure 11. - Tide Water Associated Oil Co. Blankenship project, Butler and Greenwood Counties, Kans., Jan. 1, 1956.

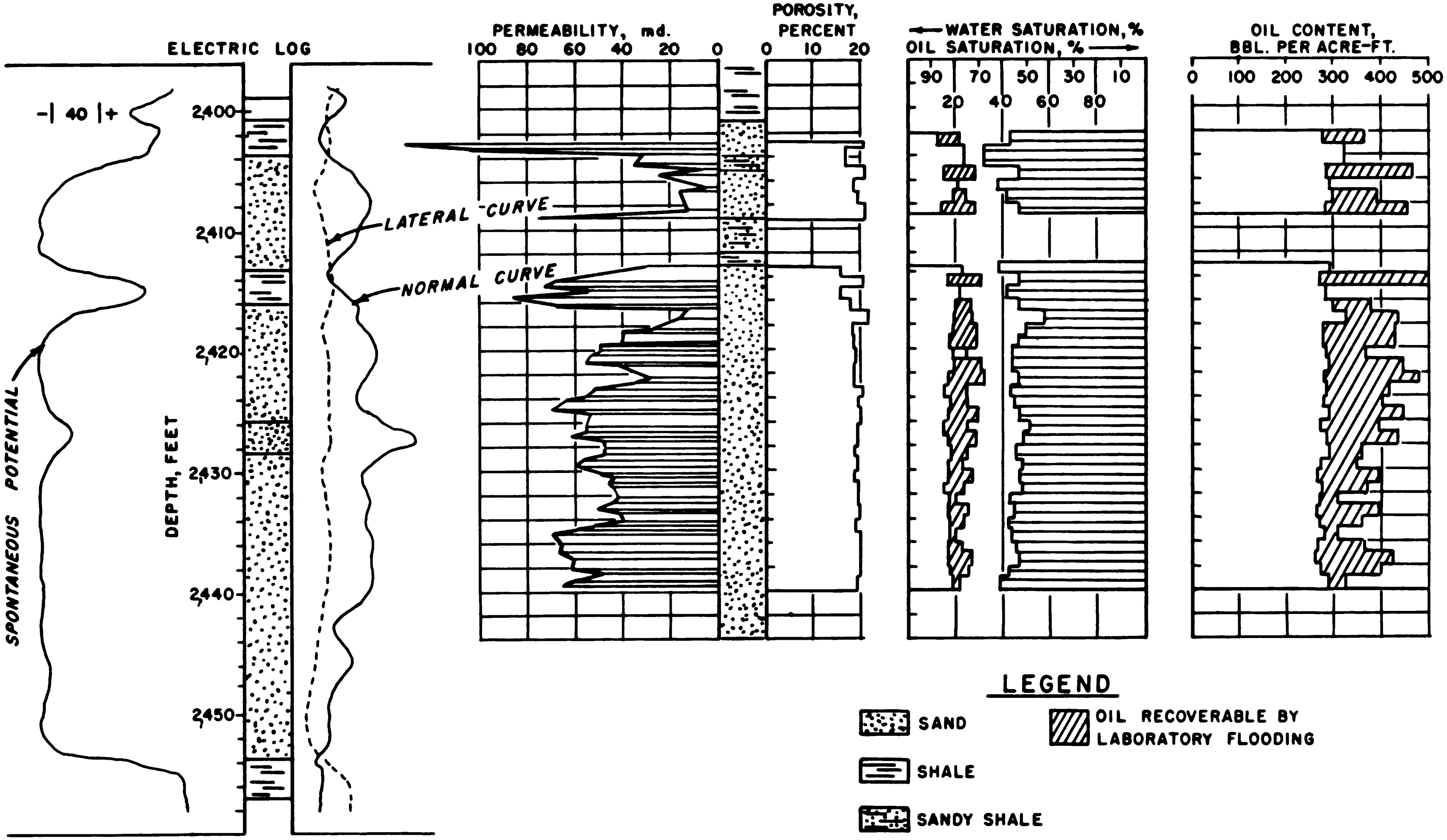

Figure 12. - Representative electric log and core analysis, Tidewater Associated Oil Co. Blankenship field, Blankenship project, Butler and Greenwood Counties, Kans.

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History Before Flooding

The discovery well of the Sallyards pool was completed on August 16, 1917, as a flowing well. Initially, oil was produced by allowing the wells to flow unrestricted until the reservoir pressure had declined to a point where they would no longer flow. The wells then were tubed for pumping. Originally each well was equipped with a pumping unit powered by a 25- to 35-hp. gas engine; later, after the rate of oil production had declined, the wells were connected to a central bandwheel power. For many years the derricks were left over the wells to facilitate pulling and servicing the wells, but most of them now have been removed.

In 1924 vacuum was applied to most of the wells in the field to stimulate the rate of production, and this practice was continued until water injection was begun. In January 1956 only one vacuum pump was in operation, and the vacuum applied was less than half the usual vacuum. The vacuum pump is of the "jerker" type and is connected by pullrods to the bandwheel power.

Method of Completing and Operating Wells

The water-input wells are drilled with rotary-drilling equipment. A 7 7/8-inch hole is drilled to the top of the sand; then a 4 7/8-inch hole is cored and reamed to bottom. If a core is not taken an electric log is obtained, and then a string of 4 1/2-inch pipe is set and cemented with 100 sacks of cement, using a Baker triplex float shoe. The cement plug then is drilled out and the sand face is washed. If the well cleans up readily, only water is used to clean the sand face; if not, approximately 50 gallons of mud acid is used and washing continued until the sand face is thoroughly clean, as evidenced by the return of clear water. These input wells are neither shot nor fractured.

New producing wells are drilled and completed in the same manner as the input wells, except that 5 1/2-inch casing is used. Old producing wells that fall within the pattern or that are suitably located with respect to the general well pattern are reworked and used in the flood. Oil wells on the edge of the producing formation, where the sand is "broken" or interbedded with shale, are drilled, cored, and cemented completely through the producing formation. An electric log is taken and the pipe perforated opposite the oil-saturated sand. The well is then hydraulically fractured, using an average of 6,000 pounds of sand and 4,000 gallons of lease oil.

The oil wells are completed with conventional tubing, rods, and pumping units. The pumping units are individually powered with gasoline or electric motors.

Source and Treatment of Water

Brine for the flood is obtained from a supply well completed at a depth of 3,570 feet in the Arbuckle limestone. The well is completed with a string of 8 5/8-inch casing set at 2,990 feet and cemented with 650 sacks of cement and with open hole to 3,570 feet. The static water level in the well is at 530 feet. A 75-hp. Reda submerged electric pump on 4-inch steel tubing is set at 1,800 feet and delivers the brine to the surface and then through a 4-inch Transite pipe to the aeration pit.

Brine produced with the oil is also in the flood and is collected in a central tank battery near the aeration pit. The produced brine from the separating tank flows into a 200-barrel skimming tank to remove any oil that might have been carried through with the water. From the skimming tank it flows through a spray-type aerator into the aeration pond, where it is mixed with the Arbuckle brine.

The Hull plant constructed in 1955 is the more modern of the two water-treating plants and will be described in detail. The method of treatment does not differ greatly in the two plants. The design of the Hull plant is shown in figure 13. Hydrogen sulfide is removed from the Arbuckle brine by aeration through use of a spray system. Water from the supply well is forced into a 4-inch steel header in the middle of the aeration pond, supported above the surface by redwood posts. Brine enters the header at a pressure of 25 p.s.i. and is sprayed into the pit through 1-inch plastic nozzles. About 25 double nozzles are used to aerate about 5,500 barrels of water per day; the pressure is regulated by varying the number of nozzles in use. Both the 1-inch couplings to the nozzles and the steel header have been coated with plastic paint (Epon) to prevent corrosion. The nozzles are 1 foot above the surface of the pond, and at the pressure applied water spray travels about 15 feet through the air before it drips into the pond. Evaporation and "carryoff" by the wind are minimized by using 6-foot-high baffles of corrugated-asbestos sheeting.

The aeration pit, which is 50 by 90 by 5 feet, is lined with Gulf-Seal, an asphaltic sealing material, to prevent water seepage. At the water's edge the surface of the sealant is plastic-coated to eliminate softening by any oil that might escape from the skimming tanks. From the aeration pond the water flows in an 18- by 18-inch, cement-lined ditch into the chemical building, where lime is fed into the water by a dry-type chemical feeder to aid in regulating the pH of the water and to stabilize carbonate saturation. The water flows by gravity from the chemical building in an open ditch 1-1/2 feet deep by 6 feet wide, sealed with Gulf-Seal. Cement blocks placed at 2-foot intervals in this ditch serve as baffles to aid in mixing the water and lime. The ditch is large enough to provide adequate detention time for much of the precipitated solids to settle out before the water flows into the settling pond. It is easier to remove the sludge from the ditch than from the settling pond; that can be done only by shutting down the entire treating system.

A row of cement blocks placed 1 inch apart forms the inner bank of the settling ditch, and between these blocks the water flows into the settling pit. The settling pit (80 by 190 by 10 feet) also is lined to prevent seepage. Three corrugated-asbestos baffles extend across the pit at intervals to regulate the flow of water through the pit. The first and third are "under" baffles, 6 feet high, with their bottoms 18 inches above the floor of the pit. The second baffle is 3-1/2 feet high and is set on the floor of the pit to act as an "over" baffle. The joints of the asbestos sheets in each baffle are caulked to prevent water seeping through the barriers. When the system is operated at full capacity, the pit will provide approximately 3 days' detention time for settling.

The water flows by gravity from the pond to the filters through approximately 900 feet of 10-inch pipe. The inlet to this line is a 60-foot section of 5-inch pipe supported in the pond by eight 55-gallon drums. An 8- by 3 1/2-foot permeable-plate-type filter charged with Graphilter is used. The plant is now operating at only 50 percent of capacity (5,000 barrels per day), so only 1 filter is used, although later, when the quantity of water required increases, a second filter will be installed. The filter is backwashed daily with a 5- by 4-inch centrifugal pump. The backwash water flows into a lined pit (30 by 30 by 5 feet), where the suspended matter is allowed to settle. The water is then returned to the aeration pit by a 1 1/2- by 1 1/2-inch centrifugal pump. The filtered water is stored in a 500-barrel wooden tank, which is connected to the intake line of the main water pumps. A F-90 National Supply horizontal-triplex pump with chromaloy pistons powered by a triple-rated electric motor pumps the treated water at a pressure of 300 p.s.i. through the distribution lines to the input wells.

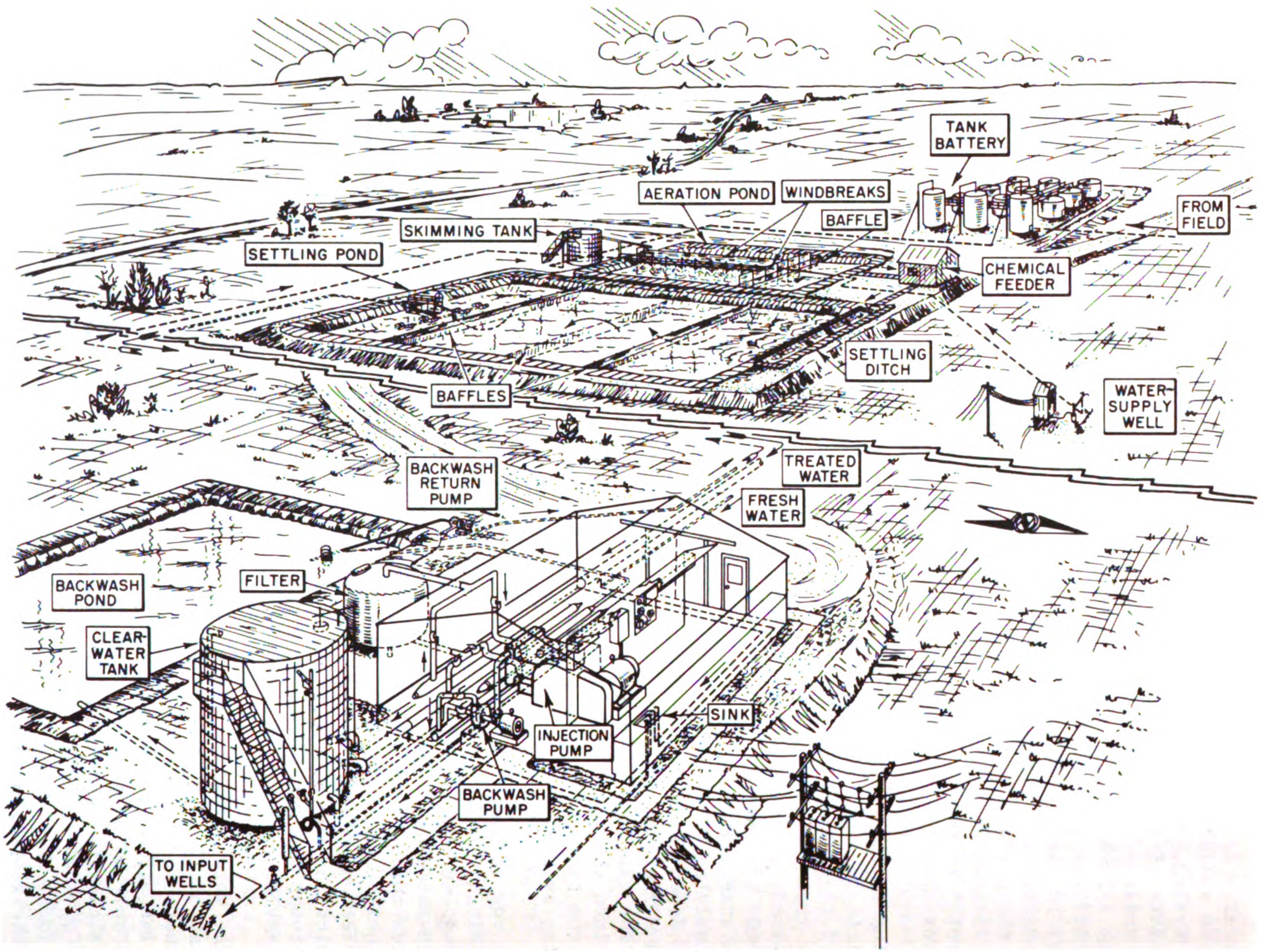

Figure 13. - Water-treating plant of Tide Water Associated Oil Co. Hull lease, Blankenship project, Greenwood County, Kans.

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Many safety devices are used throughout the system. Automatic mercury switches shut down the injection-pump motor whenever the discharge pressure raises above or declines below the predetermined values. A similar switch is installed on the oil-pressure system of the water pump, and a shear-pin relief valve is used on the high-pressure side of the pump. Low-level liquid electrodes are installed in the clear-water tank to operate a warning siren. A metal partition is installed between the injection pump and the motor, and its controls to prevent water from contact with any electrical equipment in case of a leak. A field-water analysis laboratory is installed in the pumping plant building. Mineral analyses of water samples taken at various points throughout the treating system are given in table 3.

Results of Flooding

Figure 14 shows the oil-production history of the individual leases included and of the entire Tide Water Associated Oil Co. Blankenship project. Statistical information regarding the project is given in the summary of operations.

During the first year of operation (1949) it is estimated that water injection resulted in the production of 19,000 barrels of oil that otherwise would not have been recovered. The number of active injection wells was increased from 12 to 40 in 1951, and in the following year water injection resulted in the recovery of 345,000 barrels of oil. The project has been expanded gradually during the succeeding years to maintain the rate of production above 300,000 barrels of oil annually. Figure 14 shows that the decline in the rate of oil production from the Dickenson leases has been offset largely by production from the Bryden and Stanhope leases. At the end of 1955, 65 active injection wells were affecting the recovery from 800 acres. The recovery before water injection slightly exceeded 3,600 barrels of oil per acre, and water flooding has resulted in the recovery of about 1,650,000 barrels of oil or slightly over 2,000 barrels per acre from the 800 acres flooded. The cumulative water-injected to oil-produced ratio is only 7, and a new peak rate in production is anticipated in 1956 as a result of the extension of the project in 1955. It appears probable that the ultimate recovery per acre by water flooding will equal the recovery before water injection.

TABLE 3. - Mineral analyses of flooding waters, Tide Water Associated Oil Co. Blankenship project, Butler and Greenwood Counties, Kans.

Radical	Supply well		Produced brine		Mixed brine, untreated		Clear water	
	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)
Calcium (Ca)	3,000	8.29	6,400	8.78	4,100	8.15	3,890	8.99
Magnesium (Mg)	1,210	5.51	1,715	3.85	1,470	4.81	987	4.03
Sodium (Na)	15,000	36.20	44,900	37.37	21,400	37.84	18,400	36.98
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	250	.23	121	.05	164	.10	165	.13
Sulfate (SO_4)	107	.12	192	.11	166	.14	376	.36
Chloride (Cl)	31,800	49.65	64,300	49.84	44,200	49.76	37,900	49.51
Total solids	51,367	100.00	117,628	100.00	71,500	100.00	61,718	100.00
Hydrogen sulfide (H_2S)	None		None		None		None	
Barium (Ba)	None		None		None		None	
Specific gravity	1.037		1.078		1.052		1.048	

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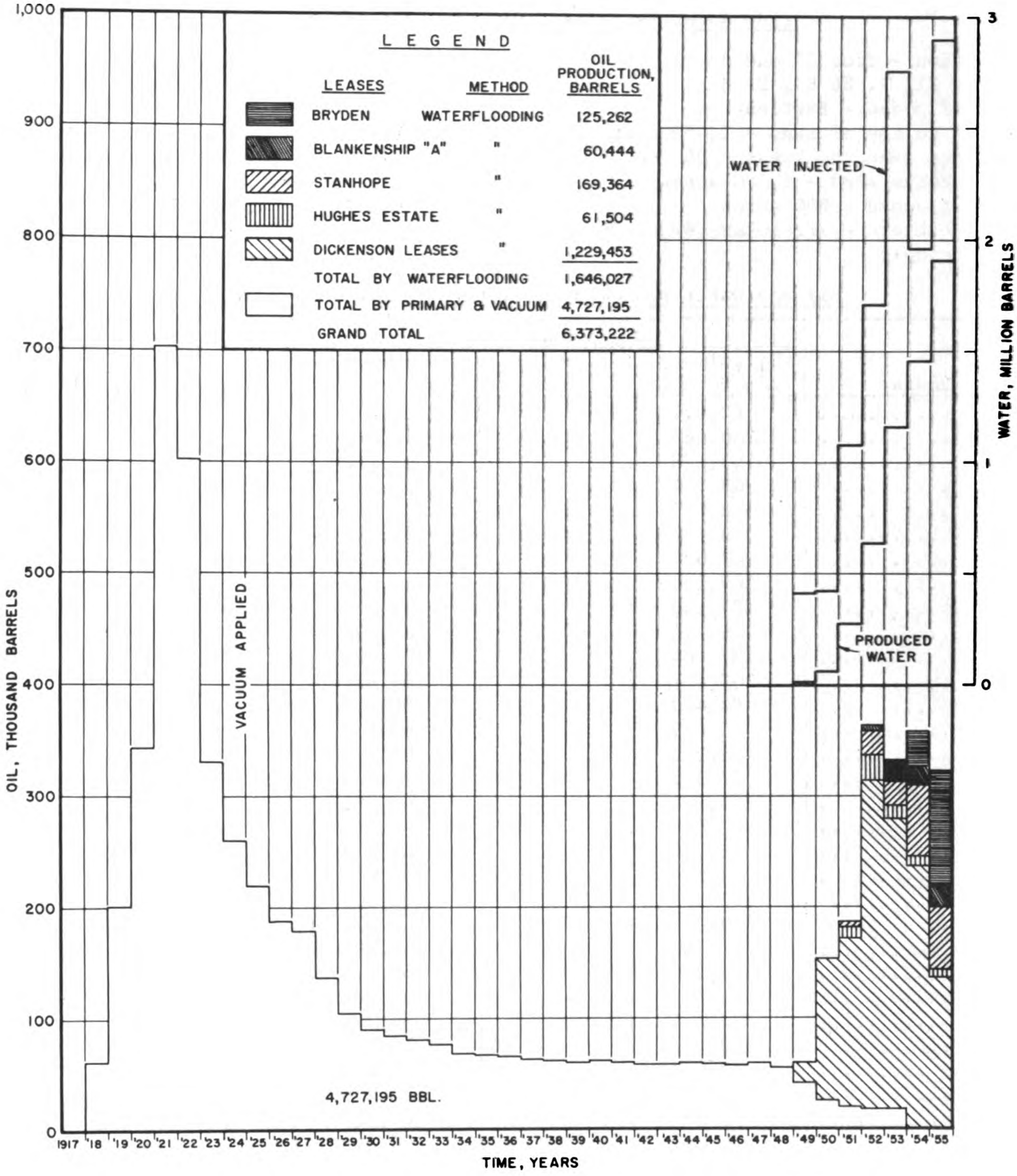

Figure 14. - Production history of Tide Water Associated Oil Co. Blankenship project, Butler and Greenwood Counties, Kans., Jan. 1, 1956.

Summary of operations
Tide Water Associated Oil Co. Blankenship project

Location - sec. 35 and 36, T. 25 S., R. 8 E. and secs. 1, 2, 9, 10, 16, 17, and 21, T. 26 S., R. 8 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,450 feet
Average sand thickness - 36 feet
Productive area - 1,300 acres
Area flooded - 800 acres
Well pattern - irregular (6- to 20-acre spacing)

Type of water - brine
Type of system - open
First injection - March 1949
First oil increase - June 1949
Status - active
Gravity of oil - 38° API
Viscosity of oil - 3.3 cp. at 100° F.

Oil and water produced and water injected, by years, bbl.

Years	Oil production			Water	
	By primary and vacuum	By water flooding	Total	Injected	Produced
1918	62,471		62,471		
1919	210,489		210,489		
1920	343,178		343,178		
1921	703,944		703,944		
1922	612,611		612,611		
1923	330,302		330,302		
1924	260,004		260,004		
1925	209,158		209,158		
1926	187,169		187,169		
1927	179,701		179,701		
1928	137,004		137,004		
1929	105,817		105,817		
1930	90,410		90,410		
1931	85,439		85,439		
1932	81,255		81,255		
1933	77,330		77,330		
1934	68,782		68,782		
1935	67,819		67,819		
1936	66,022		66,022		
1937	63,844		63,844		
1938	62,701		62,701		
1939	60,021		60,021		
1940	61,880		61,880		
1941	61,234		61,234		
1942	59,306		59,306		
1943	59,204		59,204		
1944	59,967		59,967		
1945	59,652		59,652		
1946	58,209		58,209		
1947	60,220		60,220		
1948	56,294		56,294		
1949	41,903	19,376	61,279	411,816	11,440
1950	26,137	127,219	153,356	421,319	58,062
1951	19,753	168,197	187,950	1,079,158	286,157
1952	18,886	345,275	364,161	1,712,853	637,426
1953	19,079	314,651	333,730	2,759,456	1,156,357
1954	-	358,402	358,402	1,957,283	1,456,353
1955	-	312,907	312,907	2,900,050	1,909,546
Total	4,727,195	1,646,027	6,373,222	11,241,935	5,515,341

	Bbl.
Cumulative production by primary methods and vacuum	4,727,195
Recovery per acre (1,300 acres)	3,636
Cumulative production by water flooding	1,646,027
Recovery per acre (800 acres)..	2,058
Cumulative total production to January 1, 1956	6,373,222
Total recovery per acre to January 1, 1956 (1,300 acres)	4,902
Cumulative water injected to January 1, 1956	11,241,935
Cumulative water produced to January 1, 1956	5,515,341

Summary of water-flood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected —oil-produced ratio
Dec. 31, 1949	93	12	16	208	21
Dec. 31, 1950	130	12	18	1,128	6
Dec. 31, 1951	301	40	43	1,046	6
Dec. 31, 1952	347	43	49	1,902	5
Dec. 31, 1953	454	43	53	2,147	7
Dec. 31, 1954	534	49	58	2,496	6
Dec. 31, 1955	800	65	86	2,058	7

Ohio Oil Co. Bryden-Ladd Unit Project

The pilot flood preceding development of the Ohio Oil Co. Bryden-Ladd unit project, in secs. 19, 20, 30, and 31, T. 25 S., R. 9 E., and secs. 25 and 36, T. 25 S., R. 8 E., in Greenwood County, Kans. was begun on the Ladd unit in 1946. At the end of 1955 the project had been extended to cover 537 acres as shown in figure 15.

The formation flooded is the Bartlesville sand, which is at an average depth of 2,400 feet and has an average thickness of 50 feet. The oil-bearing sand is of the shoestring type described by Bass.[7] The average porosity of the productive sand is 18 percent, but it ranges from 16 to 21 percent. The average permeability of the sand penetrated by individual wells ranges from 19 to 50 millidarcys. The average water saturation of cores taken was 55 percent and the average oil saturation 21 percent, but these values are not representative of the sand in place due to flushing of the cores by the drilling fluid. It has been estimated that the average oil saturation of the sand when water injection was begun was 48 percent. A representative electric log and core analysis of the sand are shown in figure 16.

History Before Flooding

The leases being flooded were first developed between 1918 and 1920, and a peak rate of nearly 350,000 barrels of oil per year from 537 productive acres was reached in 1924. No secondary-recovery methods were tried until 1938, when a "dump" flood was begun on the Ladd lease. Pattern flooding was begun in 1946.

Development of Flood

The initial water-flooding experiment on the property, begun in 1938, involved two injection wells. In one well (an old oil-producing well) the casing was ripped

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[7] Bass, N. W., Origin of the Shoestring Sands of Greenwood and Butler Counties, Kans.: Kansas Geol. Survey Bull. 23, 1936, 135 pp.

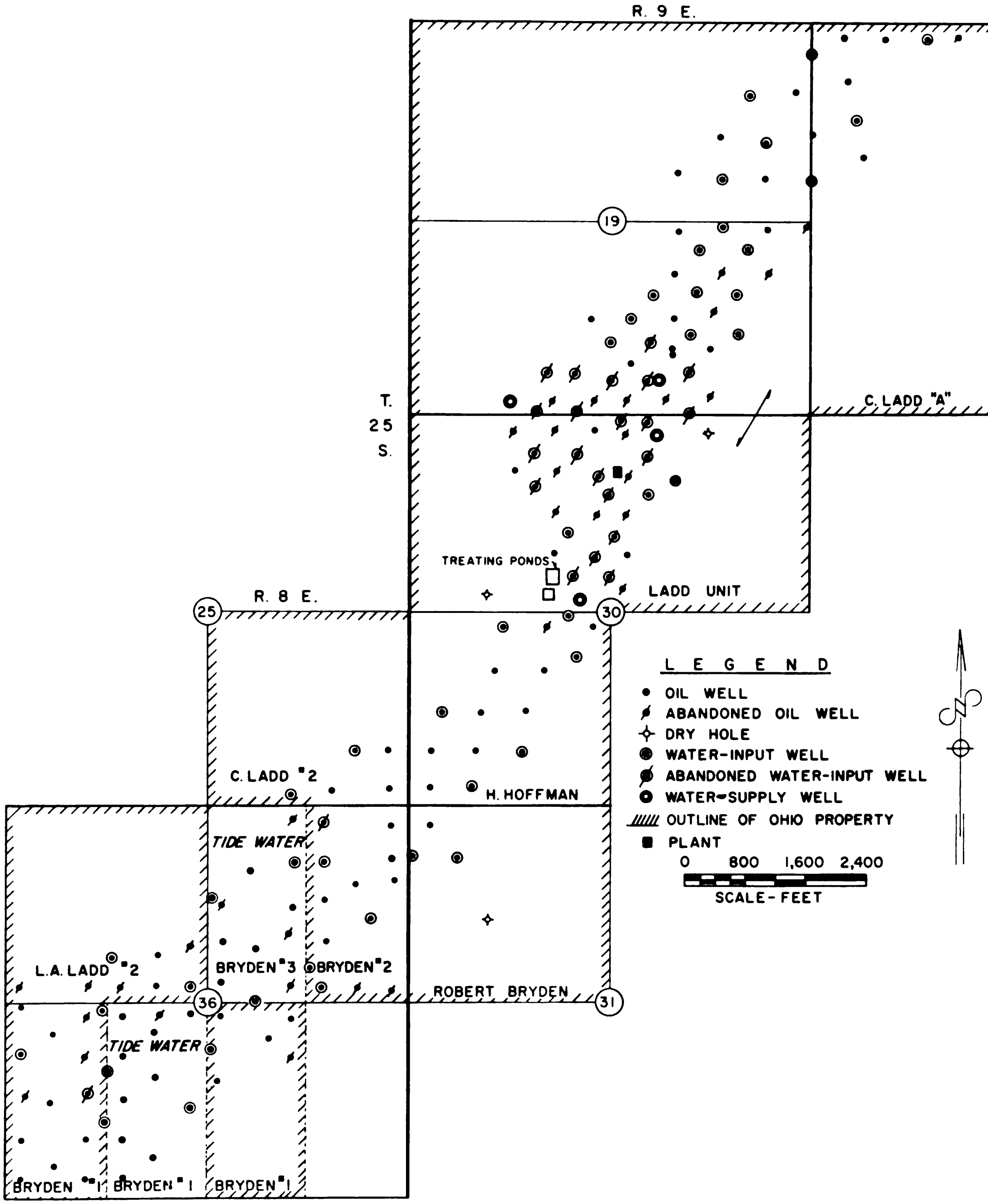

Figure 15. - Ohio Oil Co. Bryden-Ladd project, Greenwood County, Kans., Jan. 1, 1956.

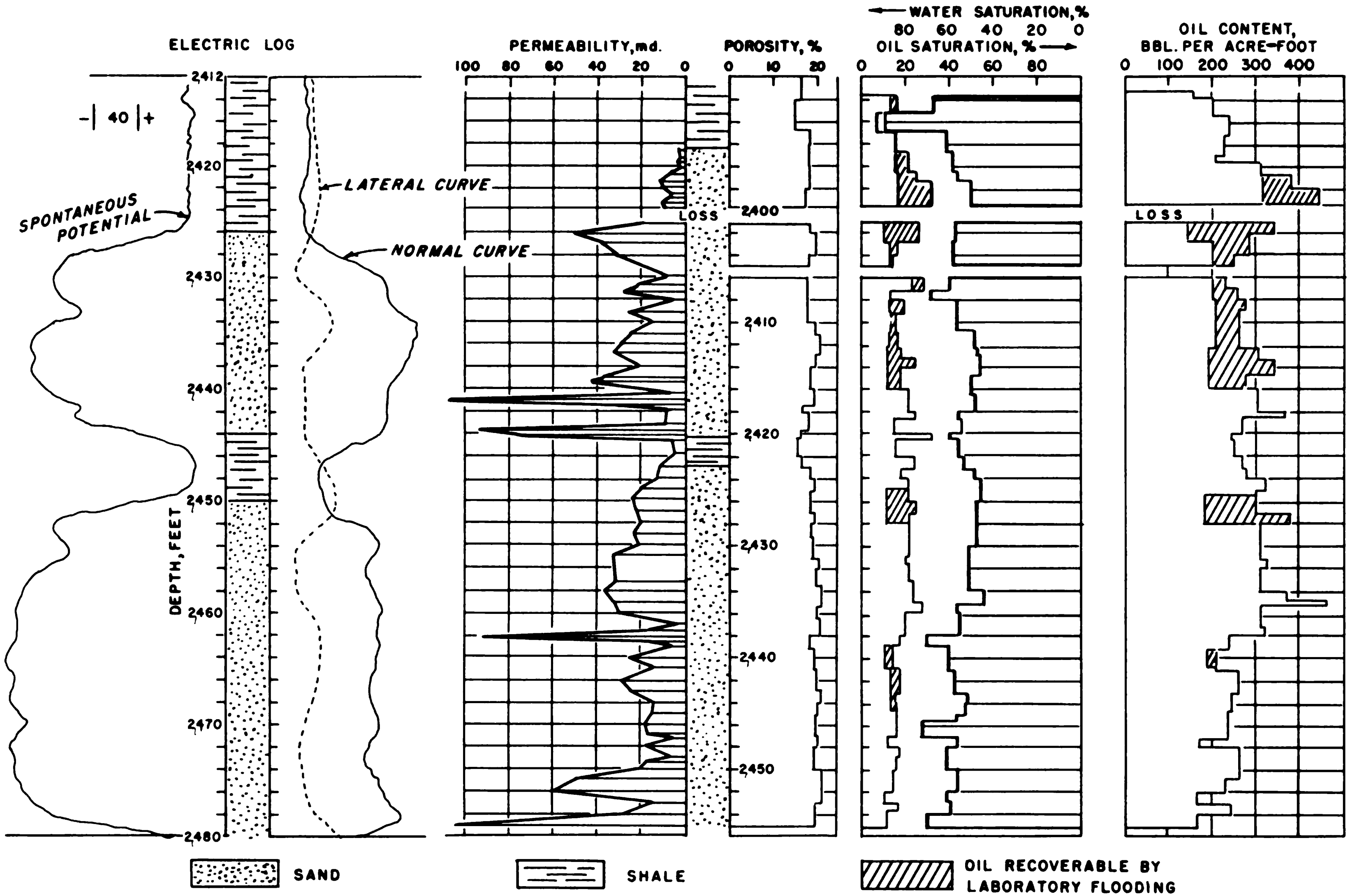

Figure 16. - Representative electric log and core analysis, Ohio Oil Co. Bryden-Ladd project, Sallyard field, Greenwood County, Kans.

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opposite the water-bearing Douglas sand, which occurs here at an average depth of 1,100 feet. The water was allowed to enter the well and flow into the Bartlesville sand under hydrostatic pressure. This well also was equipped with standard pumping equipment to pump part of the Douglas water into another old oil well that had been converted to an input well. It was estimated that 200,000 barrels of water was injected through these wells to 1944, when the operation was discontinued. Only a slight increase in the rate of oil production was obtained during the 6 years of operation.

In March 1946 a pattern pilot flood was begun on the Ladd unit. A uniform pattern of wells has not been used, as many old wells are utilized that did not fit precisely into the pattern. The original spacing averaged approximately 550 feet between like wells, but in later developments this was increased to about 800 feet. Old oil wells are used both as producing and water-input wells. By December 1950 the flood has been expanded to include 40 oil wells and 29 input wells on 205 acres. In 1951 the Ladd A and the Hoffman leases were included in the project, and in 1954 the Bryden and remaining Ladd leases were developed for water injection.

Method of Completing and Operating Wells

Old wells utilized in the flood usually are cleaned out, and the casing is reset and cemented in the top of the sand. New producing wells are drilled with a rotary rig to the top of the formation, and the oil sand is cored. The wells are cased with 5 1/2-inch pipe, and each is cemented with 100 sacks of cement. Producing wells are shot with 2 to 2 1/2 quarts of nitroglycerin per foot of pay sand and then cleaned out with cable tools. A monthly production test is made on each well with a small portable tank. The oil wells are pumped with individual units powered by electric motors; however, some of the oil wells in the older parts of the flood are converted to flowing when the water-to-oil ratio becomes excessive, and the pumping equipment is removed.

The water-input wells were completed in a similar manner, except that 4 1/2-inch pipe is used for casing. As a general rule, input wells are not shot; however, a light shot has been used in a few wells that were completed in sand of low permeability and that would not take water at the desired rate. The input wells are equipped with meters and valves to meter and control the rates of flow.

Source and Treatment of Water

Four wells completed in the Douglas formation at a depth of 1,400 feet provide water for the flood. One of these wells was previously an oil-producing well and later served as an input well for the dump flood. The 3 other supply wells were completed with 7 1/2-inch casing set at the top of the formation and cemented to the surface. One of the supply wells is equipped with a 37.5-hp. Reda submersible electric pump, and the other 3 are equipped with rods and tubing and pumped with heavy-duty pump jacks. Power for each pump jack is supplied by a 40-hp. Superior diesel engine. The water-producing capacity of the wells ranges from 1,000 to 1,500 barrels daily, but present demand does not require continuous operation of the wells.

The water-treating and pumping equipment is shown in figure 17. Produced brine and supply water enter at the top of a tray-type aerating tower, about 20 feet long and 7 feet wide, constructed of redwood and supported by 4 1/2-inch pipe cemented in the bottom of the aerating pond. Three perforated and baffled trays about 2 feet apart provided a surface to disperse the water and permit hydrogen

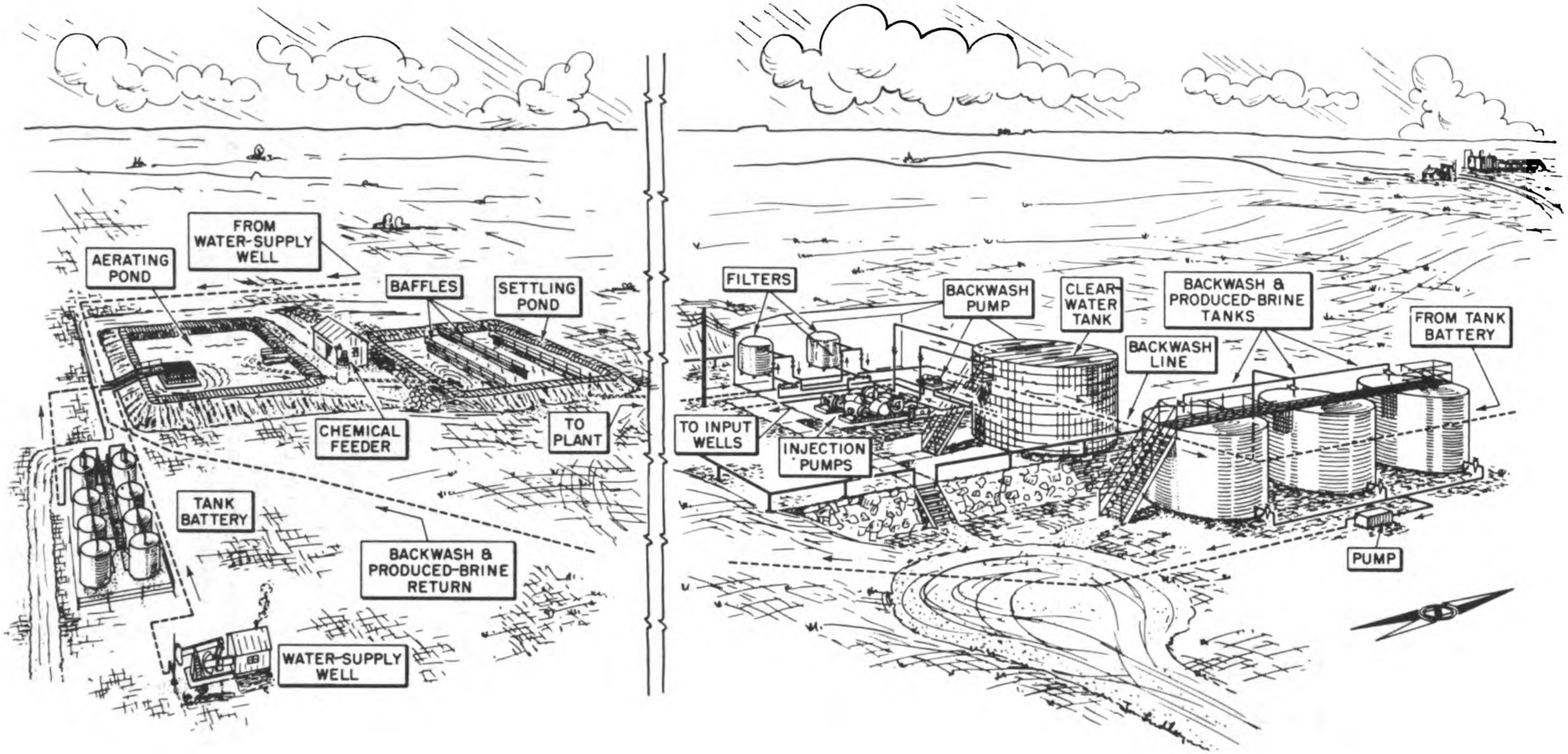

Figure 17. - Water-treating plant of Ohio Oil Co. Bryden-Ladd project, Greenwood County, Kans.

sulfide and carbon dioxide to escape and iron compounds to be oxidized. The aerating pond is 100 feet long by 75 feet wide at the ground level, has graded slopes (3:1), and is lined with an asphaltic material (Gulf-Seal) to prevent seepage.

From the aerating pond the water flows through a 7-inch conduit in the middle of the earthen separating wall into the settling pond. On the separating wall just above the conduit are 2 dry chemical feeders, 1 of which continuously adds lime to the water at the rate of 6 pounds per 100 barrels of water as the water passes through the conduit and the other adds 17 pounds of Nalco 680 daily. The settling pond is about 140 by 115 feet at water level, but the walls are sloped inward. The pit is lined with an asphaltic sealing compound to prevent seepage of the brine. Three large baffles have been constructed in the pond to prevent the water from flowing rapidly through it in a channel and to permit adequate time for the solid products of chemical reactions to settle. The water from the pond enters a 3-foot vertical section of slotted pipe and flows by gravity through the filters. Two closed-type rapid filters 8 feet in diameter by 5 feet in length, filled with graded gravel and sand, are used. Water flows into a 500-barrel, wooden, clear-water tank that supplies water to the injection pumps under a hydrostatic head of 8 feet. Treated water used to backwash the filters flows into the backwash-water tanks.

Two Oilwell 46 P pumps powered by 75-hp. electric motors force the water through the distribution lines to the wells at a plant pressure of 1,040 p.s.i. A small chemical pump has been connected into the discharge of one of the pumps, and the injection of a Nalco corrosion inhibitor is being tested.

Mineral analyses of water samples taken at various points throughout the treating system are given in table 4.

Results of Water Flooding

Figure 18 shows the production history of all the leases included in the Ohio Oil Co. Bryden-Ladd water-flooding project and the annual production by waterflooding of each lease. Wells on the Ladd unit began to respond to water injection in December 1946, a peak rate of production was reached in August 1949 of 41,000 barrels and more than 343,000 barrels was produced during 1949. Due to excessive interfingering and bypassing of injected water, the results of flooding the Ladd unit were not outstanding. A wider spacing pattern was used on the Ladd "A", Haffman, and Bryden leases to minimize this trouble. Flooding was begun on the Ladd "A" and Hoffman leases during August 1951 and on the Bryden and remaining Ladd leases in 1954. Part of the Ladd unit was abandoned in 1952, and gradual abandonment of other watered-out areas has continued. The volumes of water injected and produced are decreased, as the rate of abandonment has exceeded the rate of development. About 1,469,000 barrels of oil has been recovered by water flooding that would not have been recovered by primary-production methods. This recovery amounts to 2,735 barrels per acre compared with over 7,000 barrels per acre before water injection. This recovery by water flooding was attained with a cumulative water-injected to oil-produced ratio of about 10:1. It is apparent that the ultimate recovery by flooding will not be as high as by primary methods.

TABLE 4. - Mineral analyses of flooding waters, Ohio Oil Co. Bryden-Ladd project, Greenwood County, Kans.

Radical	Supply well		Produced brine		Mixed brine, untreated		Clear water	
	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)	P.p.m.	Reacting values, in percent (Palmer)
Calcium (Ca)	6,390	6.37	5,870	7.78	5,600	7.65	6,110	6.48
Magnesium (Mg)	3,000	5.29	1,440	3.37	1,670	4.03	1,910	3.58
Sodium (Na)	44,100	38.34	336,000	38.85	32,200	38.32	43,000	39.94
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	85	.03	140	.06	98	.04	91	.03
Sulfate (SO_4)	153	.06	248	.14	12	.01	81	.04
Chloride (Cl)	88,600	49.91	66,500	49.80	64,700	49.95	83,300	49.93
Total solids	142,328	100.00	107,798	100.00	104,280	100.00	134,692	100.00
Hydrogen sulfide (H_2S)	None		None		None		None	
Barium (Ba)	70		None		27		39	
Specific gravity	1.099		1.079		1.075		1.090	

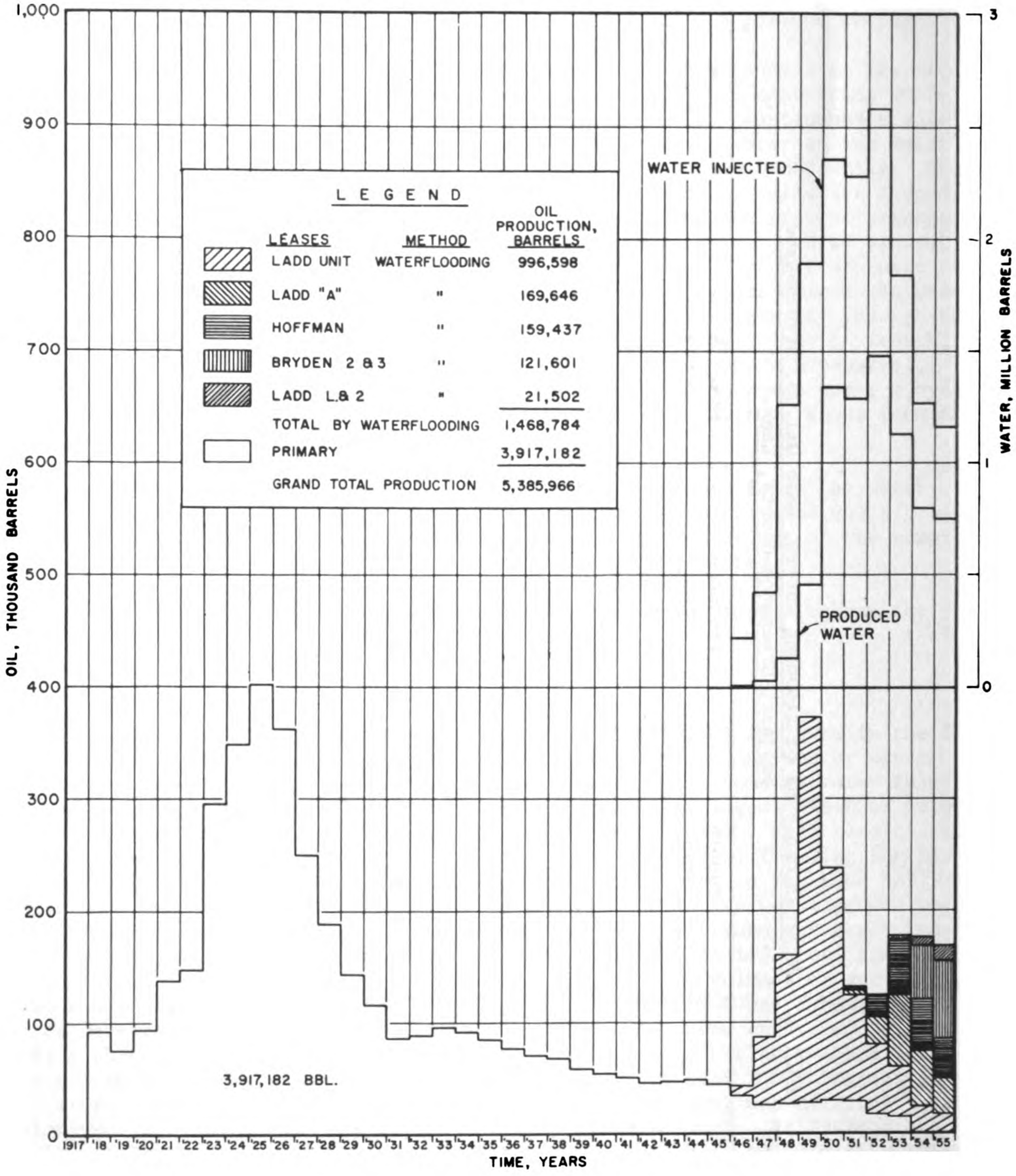

Figure 18. - Production history of Ohio Oil Co. Bryden-Ladd Unit project, Greenwood County, Jan. 1, 1956.

Summary of operations
Ohio Oil Co. Bryden-Ladd project

Location - secs. 19, 20, 30, 31, T. 25 S., R. 9 E. and secs. 25 and 36, T. 25 S., R. 8 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,400 feet
Average sand thickness - 50 feet
Productive area - 537 acres
Area flooded - 537 acres
Well pattern - irregular (550 to 800 ft. between like wells)
Type of water - Douglas brine
Type of system - open
First injection - March 1946
First oil increase - December 1946
Status - active
Gravity of oil - 38° API
Viscosity of oil - 3.5 at 100° F.

Oil and water produced and water injected, by years, bbl.

Years	Oil production			Water	
	By primary	By water flooding	Total	Injected	Produced
1917	331		331		
1918	93,589		93,589		
1919	76,903		76,903		
1920	93,836		93,836		
1921	137,815		137,815		
1922	146,926		146,926		
1923	295,174		295,174		
1924	348,680		348,680		
1925	424,915		424,915		
1926	362,973		362,973		
1927	249,255		249,255		
1928	188,602		188,602		
1929	143,118		143,118		
1930	116,113		116,113		
1931	86,537		86,537		
1932	89,135		89,135		
1933	96,118		96,118		
1934	92,524		92,524		
1935	85,143		85,143		
1936	77,399		77,399		
1937	71,599		71,599		
1938	68,273		68,273		
1939	59,275		59,275		
1940	54,239		54,239		
1941	51,742		51,742		
1942	46,993		46,993		
1943	47,523		47,523		
1944	49,680		49,680		
1945	45,060		45,060		
1946	34,169	9,698	43,867	224,044	9,296
1947	27,589	60,244	87,833	426,057	34,800
1948	28,616	131,687	160,303	1,269,366	128,000
1949	29,947	343,148	373,095	1,896,006	455,900
1950	31,717	207,213	238,930	2,360,751	1,340,363
1951	30,583	102,387	132,970	2,289,849	1,295,078
1952	18,316	107,076	125,392	2,580,302	1,473,477
1953	16,775	160,896	177,671	1,845,484	1,137,425
1954	-	176,481	176,481	1,276,823	804,314
1955	-	169,954	169,954	1,166,664	753,560
Total	3,917,182	1,468,784	5,385,966	15,335,346	7,432,213

	Bbl.
Cumulative production by primary methods	3,917,182
Recovery per acre by primary methods (537 acres)	7,295
Cumulative production by water-flooding	1,468,784
Recovery per acre by water-flooding (537 acres)	2,735
Total production to January 1, 1956	5,385,966
Total recovery per acre to January 1, 1956	10,030
Cumulative water injected to January 1, 1956	15,335,346
Cumulative water produced to January 1, 1956	7,432,213

Summary of water-flood performance

Date	Acres flooded	Active input wells	Active oil wells	Oil recovery, bbl. per acre	Cumulative water-injected —oil-produced ratio
Dec. 31, 1946	44	4	30	220	23
Dec. 31, 1947	119	18	30	588	9
Dec. 31, 1948	150	27	31	1,344	10
Dec. 31, 1949	195	29	38	2,794	7
Dec. 31, 1950	205	29	40	3,668	8
Dec. 31, 1951	319	41	54	2,678	10
Dec. 31, 1952	342	42	51	2,811	11
Dec. 31, 1953	422	33	45	2,660	11
Dec. 31, 1954	537	34	46	2,419	11
Dec. 31, 1955	537	31	50	2,735	10

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